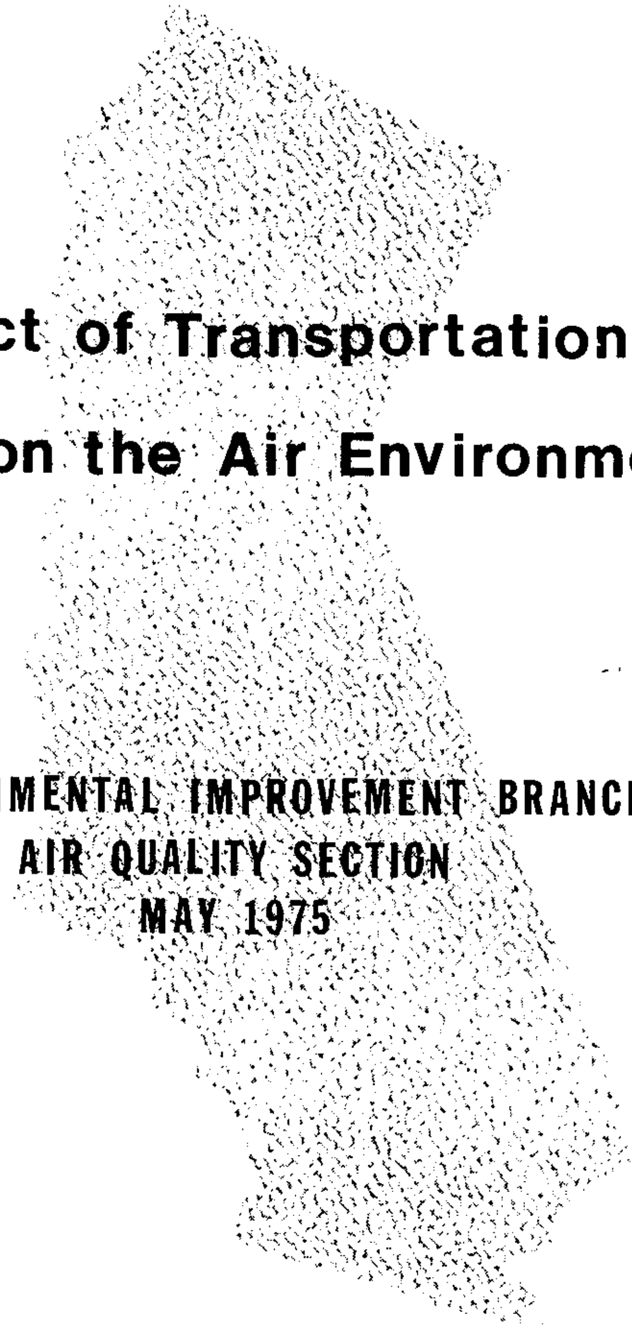
AIR QUALITY TRAINING MANUAL



Impact of Transportation Systems on the Air Environment

ENVIRONMENTAL IMPROVEMENT BRANCH
AIR QUALITY SECTION
MAY 1975

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

45. For an air quality survey, the minimum distance separating CO air sensors and localized sources is:

a. 0 - 100 ft.
b. 200 - 400 ft.
c. 600 - 800 ft.
d. None of these

46. In general, the O_3 concentrations are the highest during the:

a. summer and fall
b. summer and winter
c. winter and spring

47. In general, the highest daily O_3 concentrations occur in

a. early morning
b. midday
c. evening

48. In general, the maximum CO concentrations occur in:

a. winter
b. spring
c. summer
d. fall

49. The transport of pollutants from one city to another is most likely to occur with:

a. light winds, surface based inversion
b. strong winds, surface based inversion
c. light winds, elevated inversion
d. strong winds, elevated inversion

FOREWORD

The information in these lecture notes are for a one week air quality training course entitled "Impact of Transportation Systems on the Air Environment". This course is given to the Transportation Districts (Environmental and Transportation Planners and Engineers) for the purpose of providing information on how to conduct an air quality study. This involves the gathering of air quality field data, the analyses of such data, uses of air quality models, and the writing of an air quality report.

These notes update material in the following air quality training manuals:

1. Meteorology and Its Influence on the Dispersion of Pollutants From Highway Line Sources.

2. Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality.

3. Traffic Information Requirements for Estimates of Highway Impact on Air Quality.

4. Mathematical Approach to Estimating Highway Impact on Air Quality.

5. Appendix to Volume 4.

6. Analysis of Ambient Air Quality for Highway Projects.

7. A Method of Analyzing and Reporting Highway Impact on Air Quality.

The changes and modifications presented in these notes arise from the Transportation Laboratory research findings over the past three years and Transportation Districts experiences and problems in conducting air quality studies. These lecture notes are to be used as a supplement to the lectures. They are not intended to be complete or self sufficient.

ACKNOWLEDGEMENTS

These notes have been authored by Andrew J. Ranzieri under the supervision of Earl C. Shirley, Chief, Environmental Improvement Branch. Acknowledgement is given to Kenneth O. Pinkerman of the Transportation Laboratory who developed the material for air quality instrumentation section. Also acknowledged is Michael D. Batham who prepared the section on emission factors. Special acknowledgement is given to the simulation modeling group at the laboratory, Gerald R. Bemis, Paul D. Allen, and Charles E. Ward for their assistance in preparing the sections on air quality modeling.

Further acknowledgement is given to Earl C. Shirley for his assistance in the preparation of sections on legal requirements, and air quality monitoring.

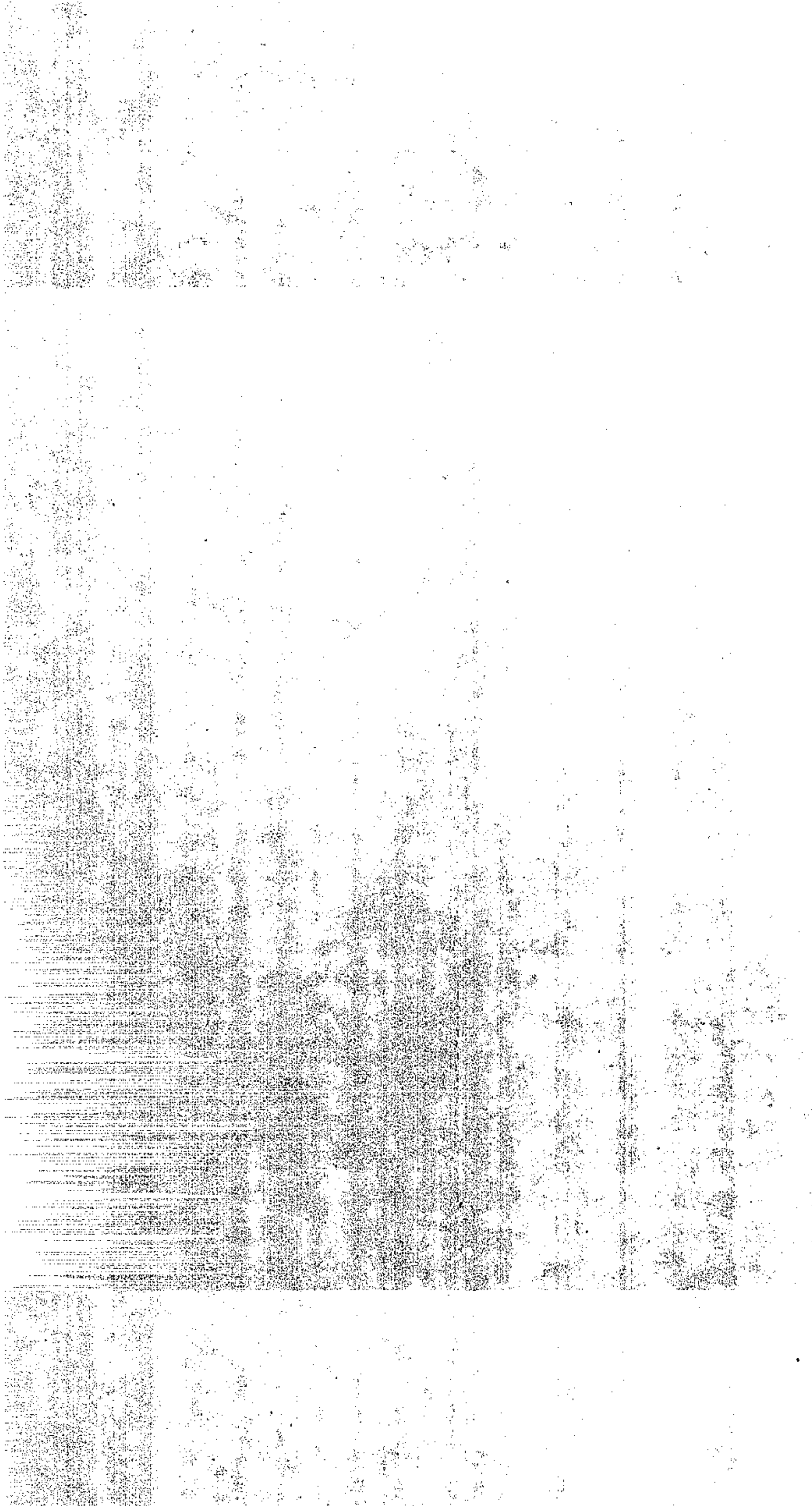


TABLE OF CONTENTS

		Page
SECTION 1 -	Introduction and Legal Requirements	1
SECTION 2:	Fundamentals of Air Quality	19
SECTION 3:	Traffic Requirements for Transportation Impact Studies.	40
SECTION 4:	Emission Factors For Motor Vehicles	61
SECTION 5:	Air Pollution Meteorology and Atmospheric Turbulence	95
SECTION 6:	Reduction of Meteorological Data and Meteorological Surveys	149
SECTION 7:	Air Quality Monitoring and Analysis	154
SECTION 8:	Air Quality Surveys	166
SECTION 9:	Air Quality Instrumentation	187
SECTION 10:	Air Quality Modeling	195
SECTION 11:	Sensivity Analysis	212
SECTION 12:	Line Source Diffusion Model (CALINE2)	216
SECTION 13:	Regional Air Quality Modeling	295
SECTION 14:	Reports	342
APPENDIX A:	References	358
SECTION 15:	Problems	362

SECTION 1

INTRODUCTION AND LEGAL REQUIREMENTS

I. Introduction of Instructors

A. Welcoming comments

B. Introduction of course personnel and history of the course.

C. Organization of course participants into work groups for problem sessions.

D. Reference books and materials - See Appendix A.

II. Course Objectives and Goals

A. Discuss legislation passed that requires that transportation planners and engineers to provide EIS and air quality studies.

B. To explain the inter-relationship of air quality reports and the EIS.

C. To define the elements and discuss the procedures in assessing the impact of transportation systems on the air environment.

D. To provide the course participants with the necessary background to conduct, supervise or contract out air quality studies.

E. Overview of Course - Figure #1-1

1. Legal Requirements

2. Inputs - Traffic, Meteorology, Emission Factor, Ambient Air Quality

3. Analysis - Air Quality Modeling, Microscale and Mesoscale

4. Air Quality Report

III. Define EIS

A. It is a disclosure document. It is designed to provide information to decision makers.

B. It should discuss positive and negative environmental impacts.

C. It should not "cover up" anything.

IV. Transportation Planning With Environmental Inputs.

A. Historically environmental concerns were not part of planning process

B. Discuss the FHWA "Short Course on Transportation Planning Process 3-C"; 3-C = comprehensive, cooperative and continuing.

C. See Figure No. 1-2

ELEMENTS OF THE COURSE

(OR HOW DO WE GET THERE FROM HERE?)

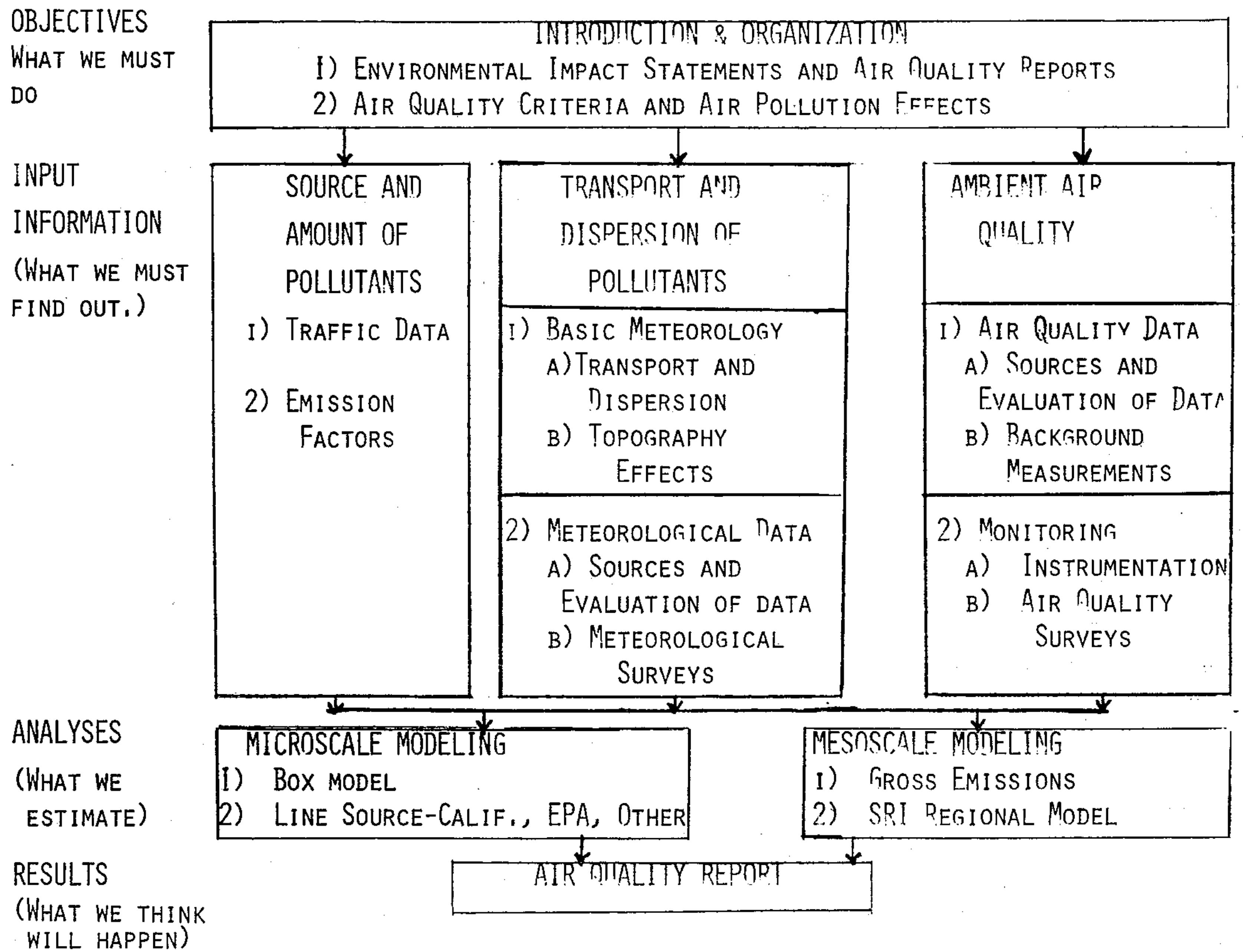


FIGURE 1-1

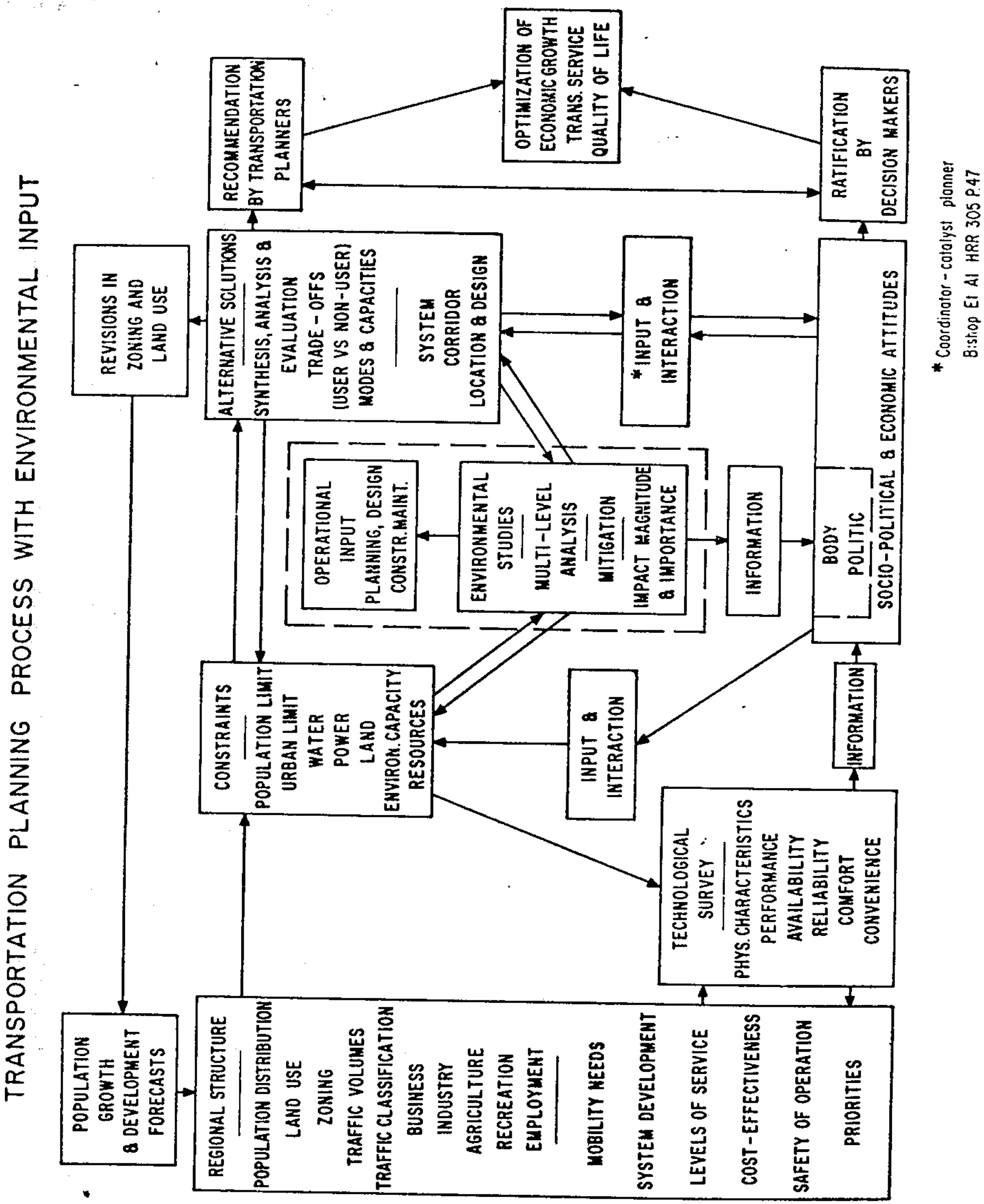

TRANSPORTATION PLANNING PROCESS WITH ENVIRONMENTAL INPUT
POPULATION GROWTH & DEVELOPMENT FORECASTS
REGIONAL STRUCTURE
POPULATION DISTRIBUTION
LAND USE
ZONING
TRAFFIC VOLUMES
TRAFFIC CLASSIFICATION
BUSINESS
INDUSTRY
AGRICULTURE
RECREATION
EMPLOYMENT
MOBILITY NEEDS
SYSTEM DEVELOPMENT
LEVELS OF SERVICE
COST-EFFECTIVENESS
SAFETY OF OPERATION
PRIORITIES
REVISIONS IN ZONING AND LAND USE
CONSTRAINTS
POPULATION LIMIT
URBAN LIMIT
WATER
POWER
LAND
ENVIRON. CAPACITY
RESOURCES
TECHNOLOGICAL SURVEY
PHYS. CHARACTERISTICS
PERFORMANCE
AVAILABILITY
RELIABILITY
COMFORT
CONVENIENCE
INPUT & INTERACTION
INFORMATION
OPERATIONAL INPUT PLANNING, DESIGN CONSTR. MAINT.
ENVIRONMENTAL STUDIES
MULTI-LEVEL ANALYSIS
MITIGATION
IMPACT MAGNITUDE & IMPORTANCE
INFORMATION
BODY POLITIC
SOCIO-POLITICAL & ECONOMIC ATTITUDES
ALTERNATIVE SOLUTIONS
SYNTHESIS, ANALYSIS & EVALUATION
TRADE-OFFS (USER VS NON-USER)
MODES & CAPACITIES
SYSTEM CORRIDOR LOCATION & DESIGN
* INPUT & INTERACTION
RECOMMENDATION BY TRANSPORTATION PLANNERS
OPTIMIZATION OF ECONOMIC GROWTH TRANS. SERVICE QUALITY OF LIFE
RATIFICATION BY DECISION MAKERS
* Coordinator - catalyst planner
Bishop Et Al HRR 305 P.47

FIGURE 1-2

V. Detailed Inputs to EIS

A. See Figure 1-3

B. 1st Level of Analysis - System Planning

C. 2nd Level of Analysis - Project Level

D. Mitigation Measures Air Quality

1. Raised highway section

2. Locate highway further from receptors

3. Space highways to minimize air pollution to allow for transport and diffusion

4. Purchase wider right-of-way

5. Provide highway with wide median to allow diffusion of pollutants

VI. Details of Air Quality Study

A. See Figure 1-4

B. Construction Guidelines and Controls

1. Fugitive dust - Water subgrade or use dust pallative. Refer to State of California Standard Specifications.

2. Control emissions from construction equipment, concrete and asphalt plants

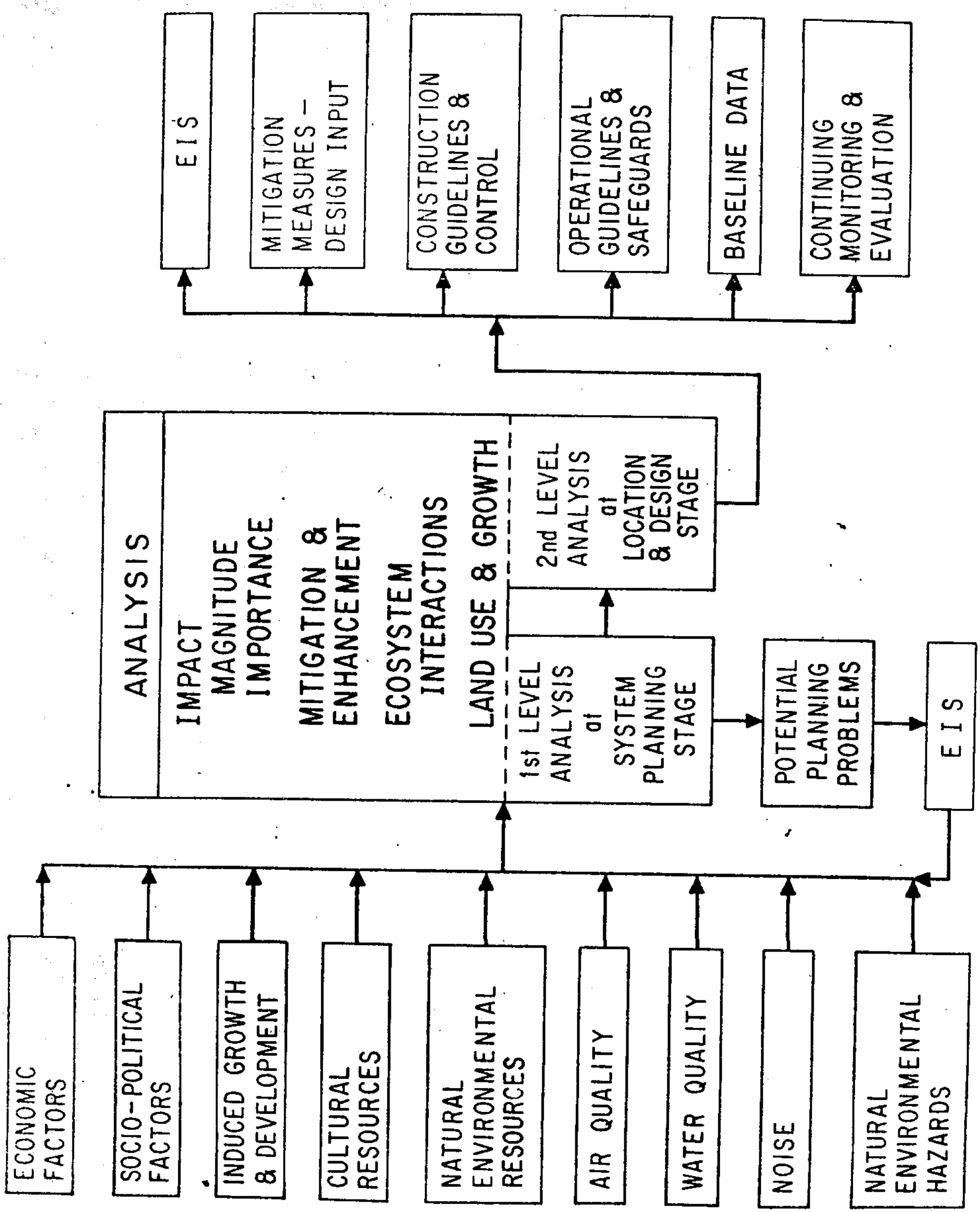
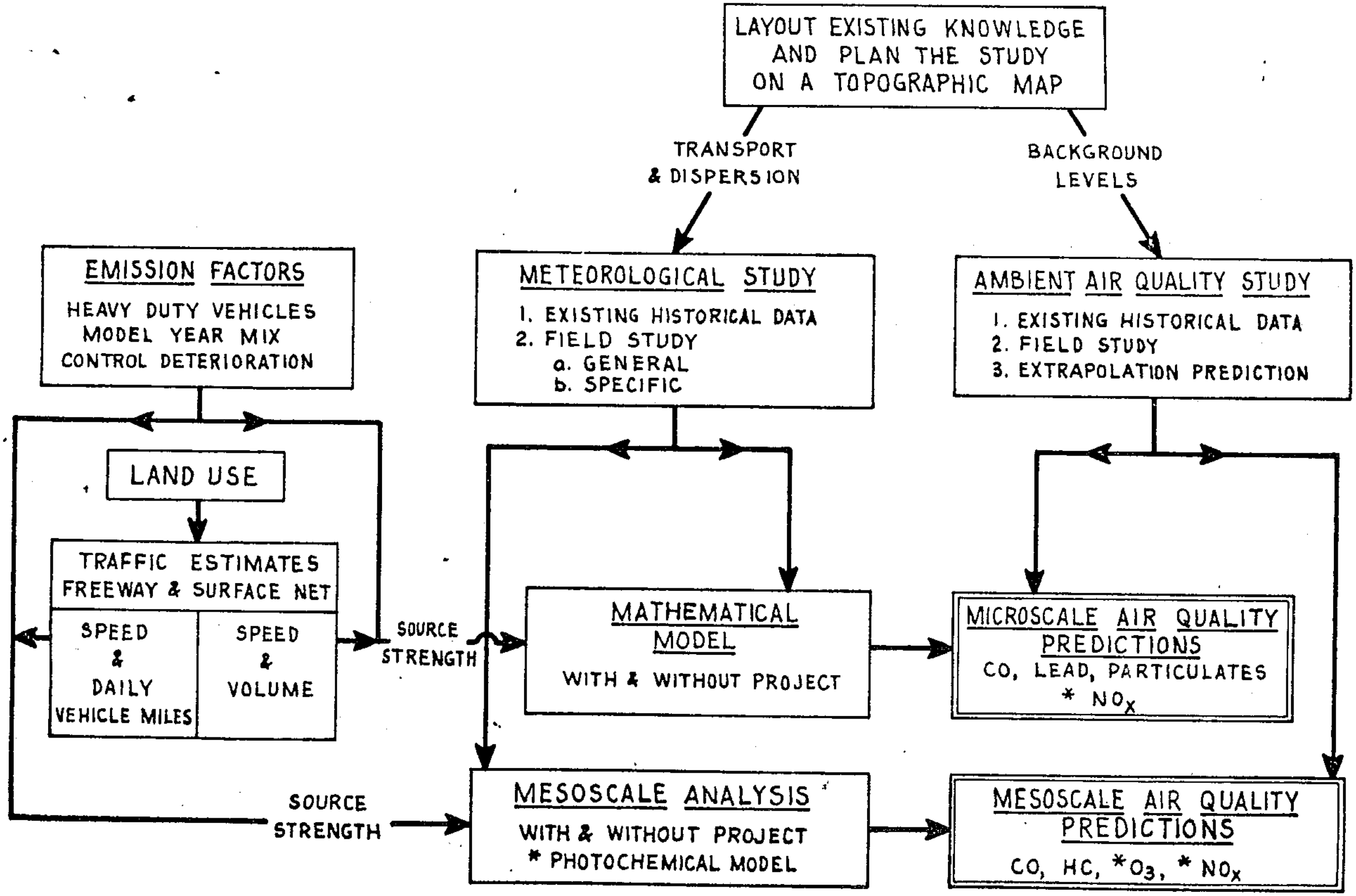

ECONOMIC FACTORS
SOCIO-POLITICAL FACTORS
INDUCED GROWTH & DEVELOPMENT
CULTURAL RESOURCES
NATURAL ENVIRONMENTAL RESOURCES
AIR QUALITY
WATER QUALITY
NOISE
NATURAL ENVIRONMENTAL HAZARDS
ANALYSIS
IMPACT MAGNITUDE IMPORTANCE
MITIGATION & ENHANCEMENT
ECOSYSTEM INTERACTIONS
LAND USE & GROWTH
1st LEVEL ANALYSIS at SYSTEM PLANNING STAGE
2nd LEVEL ANALYSIS at LOCATION & DESIGN STAGE
POTENTIAL PLANNING PROBLEMS
E I S
E I S
MITIGATION MEASURES — DESIGN INPUT
CONSTRUCTION GUIDELINES & CONTROL
OPERATIONAL GUIDELINES & SAFEGUARDS
BASELINE DATA
CONTINUING MONITORING & EVALUATION

FIGURE 1-3

PROCEDURE FOR ANALYSING HIGHWAY IMPACT ON AIR QUALITY



* TO BE ADDED AT A LATER DATE.

FIGURE 1-4

3. Clearing the highway alignment from vegetation growth, how are you going to dispose of it? Burn?

C. Operational Guidelines and Controls

1. Collect the debris from highways, how are you going to dispose of it.

2. Oil Spills, what procedures are going to be taken to clean-up.

3. Exposure time for maintenance men on highways, truck drivers in heavy congested traffic

D. Baseline Data

1. Continue to monitor to "close the loop" to see how well our predictions match actual field values.

2. Information for future planning - 3-C program

VII. Background on Legal Requirements

A. Professional Development of Transportation Engineering

1. Agrarian Farmer - dirt roads

2. Industrial Revolution - required designing structural sections to handle heavy loads to transport products.

3. Recreational Highways - people become more affluent more leisure time for camping, boating, etc.

4. Esthetics - transportation planner became concerned about the visual impact of highways.

5. Safety of Drivers - engineers were concerned with skid resistant pavements, median barriers, etc. All this time our profession is expanding and dynamic expressing the desires of the public.

6. Environmental Protection - private citizens, Sierra Club and special organized groups wanted environmental protection. Eventually politicians reacted and passed laws to include environmental concern.

7. See Figures 1-5, 1-6, 1-7, 1-8, and 1-9

   .Clean Air Amendments
   .National and State Air Quality Standards
   .FHWA Guidelines
   .EPA Indirect Source Regulations

8. Summary of Legal Requirements for Project Level and System Planning Analysis. See Figure 10.

9. Laws Require Answers to the Following Questions:

- What is the anticipated impact on air quality if the transportation facility were built? If not built?

- What adverse effects on air quality could not be avoided if the proposed transportation facility were built? If not built?

- How would the relationship between local short term uses of the air resources and maintenance and enhancement of long term productivity be affected if the transportation facility were built? If not built?

- What irreversible and irretrievable commitments of the air resource would be involved if the transportation facility were built? If not built?

- What mitigation measures could be implemented to minimize the impact if the transportation facility were built?

- Is the project consistent with the attainment of air quality standards for the proposed basin?

- To what extent would community growth be enhanced if the proposed transportation facility were built? If not built? How would this effect local air quality?

MAJOR LAWS AND REGULATIONS GOVERNING AIR QUALITY IMPACT STUDIES FOR HIGHWAY PROJECTS

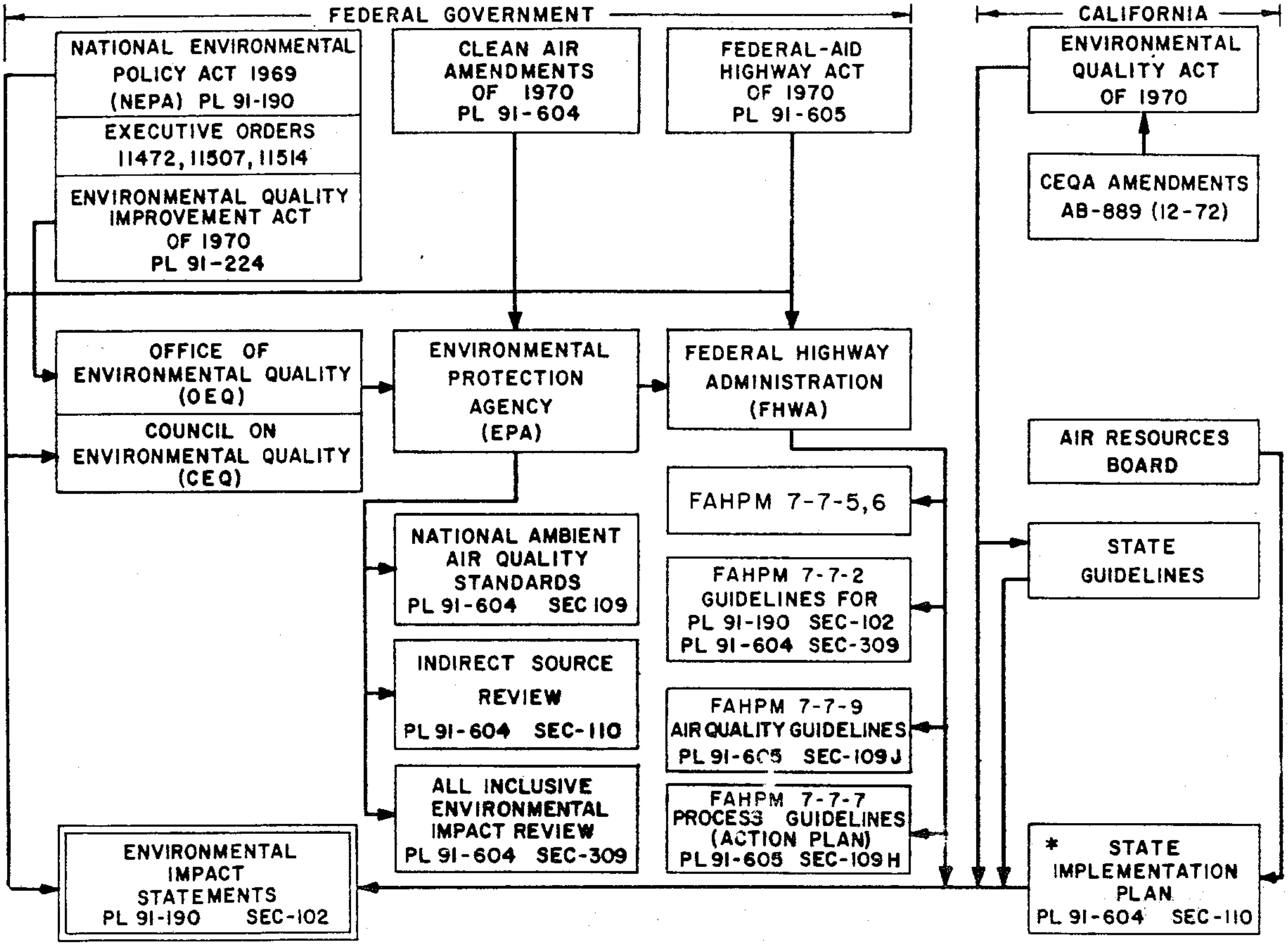


FIGURE 1-5

NATIONAL PRIMARY AMBIENT AIR QUALITY STANDARDS

POLLUTANT	STANDARD
CARBON MONOXIDE (CO)	35 ppm[1] (MAX. 1 HR. CONC.)[2] 9 ppm (MAX. 8 HR. CONC.)[2]
PHOTOCHEMICAL OXIDENT (O_x)	0.08 ppm (MAX. 1 HR. CONC.)[2]
HYDROCARBONS (HC)[3]	0.24 ppm (MAX. 3 HR. CONC., 6 - 9 a.m.)[2]
NITROGEN DIOXIDE (NO_2)	0.05 ppm (ANNUAL ARITHMETIC MEAN, A.A.M.)
SULFUR OXIDES (SO_2)	0.03 ppm (A.A.M.) 0.14 ppm (MAX. 24 HR. CONC.)[2]
PARTICULATE MATTER	260 MICROGRAMS/CUBIC METER (MAX. 24 HR. CONC.)[2]

1. ppm = PARTS PER MILLION
2. NOT TO BE EXCEEDED MORE THAN ONCE PER YEAR
3. HC STANDARD SET AS A GUIDE IN DEVISING IMPLEMENTATION PLANS TO ACHIEVE OXIDANT STANDARDS

INDIRECT SOURCE REGULATIONS

INDIRECT SOURCE: A FACILITY, BUILDING, STRUCTURE OR INSTALLATION WHICH ATTRACTS OR MAY ATTRACT MOBILE SOURCE ACTIVITY THAT RESULTS IN AN EMISSION FOR WHICH THERE IS A NATIONAL STANDARD.

INDIRECT SOURCES:

(a.) HIGHWAYS & ROADS
(b.) PARKING FACILITIES
(c.) RETAIL, COMMERCIAL & INDUSTRIAL FACILITIES
(d.) RECREATION, AMUSEMENT, SPORTS AND ENTERTAINMENT FACILITIES.
(e.) AIRPORTS
(f.) OFFICE AND GOVERNMENT BUILDINGS
(g.) APARTMENT & CONDOMINIUM BUILDINGS
(h.) EDUCATION FACILITIES

FIGURE 1-7

INDIRECT SOURCE REGULATIONS

FOR STANDARD METROPOLITAN STATISTICAL AREAS
(U.S. BUREAU OF THE BUDGET)

PERMITS FOR CONSTRUCTION ARE REQUIRED IF
(INSIDE SMSA)

(a.) ANY NEW PARKING FACILITY OR PARKING AREA WITH CAPACITY OF 1000 CARS OR MORE.

(b.) ANY MODIFIED PARKING FACILITY WHICH INCREASE PARKING CAPACITY BY 500 VEHICLES OR MORE.

(c.) ANY NEW HIGHWAY SECTION THAT ATTAINS 20,000 OR MORE VEHICLES PER DAY WITHIN TEN YEARS OF CONSTRUCTION.

(d.) ANY MODIFIED HIGHWAY WHICH WILL INCREASE TRAFFIC VOLUME BY 10,000 OR MORE VEHICLES PER DAY WITHIN TEN YEARS..

FIGURE 1-8

INDIRECT SOURCE REGULATIONS

PERMITS FOR CONSTRUCTION OUTSIDE SMSA:

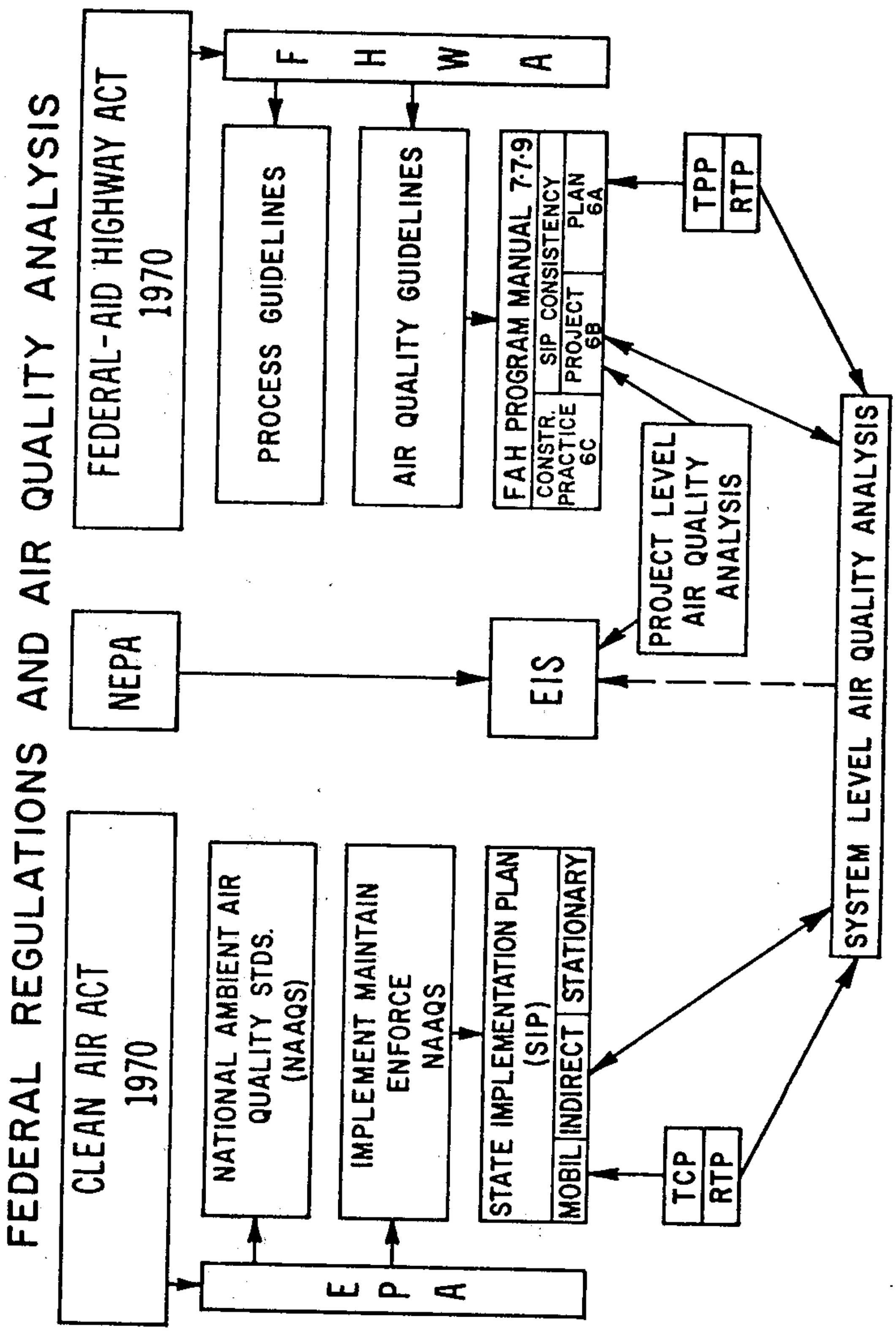
(a) ANY NEW PARKING FACILITY OR PARKING AREA WHICH HAS A CAPACITY OF 2000 CARS OR MORE.

(b) ANY MODIFIED PARKING FACILITY WHICH INCREASE CAPACITY BY 1000 CARS OR MORE.

(c) NEW AIRPORT: WITHIN 10 YEARS, 50,000 OR MORE OPERATIONS PER YEAR BY REGULARLY SCHEDULED AIR CARRIERS, OR USE BY 1,600,000 OR MORE PASSENGERS.

(d.) MODIFIED AIRPORT: WITHIN 10 YEARS, INCREASE OF 50,000 OR MORE OPERATIONS OR INCREASE OF 1,600,000 PASSENGERS OR MORE.

FIGURE 1-9



FEDERAL REGULATIONS AND AIR QUALITY ANALYSIS
CLEAN AIR ACT 1970
NEPA
FEDERAL-AID HIGHWAY ACT 1970
E P A
F H W A
NATIONAL AMBIENT AIR QUALITY STDS. (NAAQS)
IMPLEMENT MAINTAIN ENFORCE NAAQS
STATE IMPLEMENTATION PLAN (SIP)
MOBIL
INDIRECT
STATIONARY
EIS
PROCESS GUIDELINES
AIR QUALITY GUIDELINES
F A H PROGRAM MANUAL 7·7·9
SIP CONSISTENCY
CONSTR. PRACTICE 6C
PROJECT 6B
PLAN 6A
PROJECT LEVEL AIR QUALITY ANALYSIS
TPP
RTP
TCP
RTP
SYSTEM LEVEL AIR QUALITY ANALYSIS

FIGURE 1-10

VIII. EPA Reviews of EIS

A. EPA rating of a transportation project is published in the Federal Register.

B. Rating System

1. Environmental Impact of Project

LO = lack of objection

ER = environmental reservations; they feel that alternatives or modifications of the project should be studied.

EU = environmentally unsatisfactory; they consider the project detrimental to the environment.

2. Adequacy of material in EIS for review.

Category: 1 = adequate

2 = insufficient information to make judgment

3 = inadequate

A rating of "2" or "3" above indicates that transportation engineers have not exercised their professional responsibility. They have not provided enough information to enable an evaluation of the impact.

XI. Action to Stop Transportation Projects

A. No EIS - many court decisions have made NEPA retroactive. Example: Route 101 in Los Angeles.

B. Adequacy of EIS - legal interpretation

C. Qualifications of personnel, methods of sampling, analysis, modeling, etc.

D. Challenge the court decision to approve EIS.

SECTION 2

FUNDAMENTALS OF AIR QUALITY

I. Scales of Analysis For Air Quality Studies

A. Reasons for Scales of Analysis

1. Meteorological processes - diffusion, wind speeds and direction, insolation, inversions characteristics, etc., vary in kind and intensity with scale.

2. Receptor locations in regards to pollutant transport.

3. Emission flux variations.

4. Photochemical reactions are large scale problems.

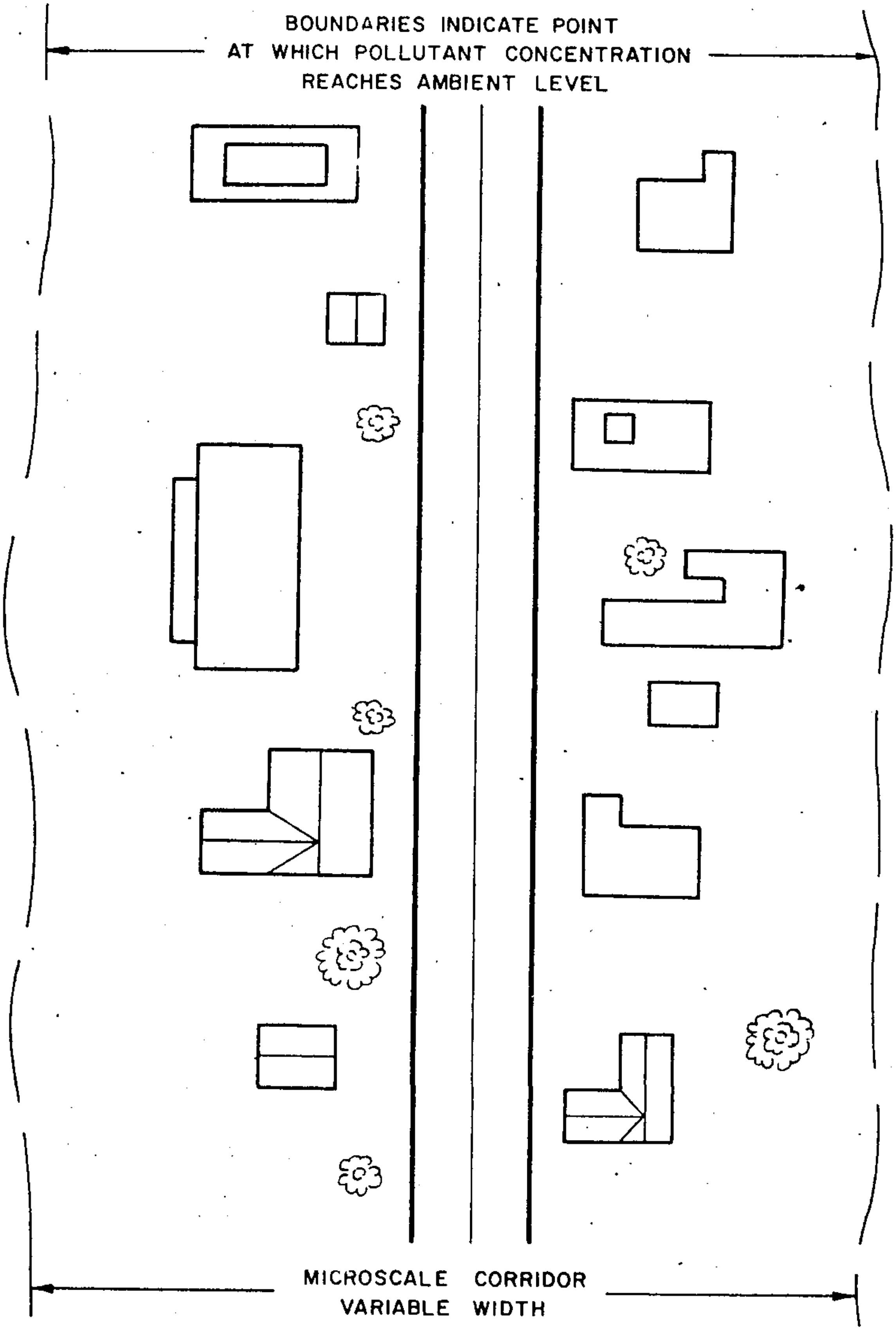
B. Microscale (Corridor)

1. Applies to the pollutant concentrations in the immediate vicinity of the roadway.

2. The boundary of this region can extend up to 1000 feet either side of the roadway.

3. This scale is concerned with the elevated concentrations of pollutants to which people living adjacent to the roadway are subjected.

4. See Figure 2-1



MICROSCALE ANALYSIS

FIGURE 2-1

C. <u>Mesoscale</u>

1. Applies to the area around the corridor where the surface street and freeway networks are significantly affected.

2. This applies to traffic volumes and route speeds.

3. See Figure 2-2.

D. <u>Basin</u>

1. This refers to the region over which most of the atmospheric mixing of air pollutants generated by vehicles and industry takes place.

2. This can be considered to be an air basin as described by ARB.

3. See Figure 2-2.

II. Sources of Air Pollution

A. Stationary Sources

1. power plants
2. industrial installations
3. oil refineries
4. domestic heaters

B. Mobile Sources

1. motor vehicles
2. aircraft
3. shipping
4. railroads

NATIONWIDE POLLUTANT EMISSIONS BY WEIGHT
MILLION TONS PER YEAR 1970

Source	CO	Particulates	SO_x	HC	NO_x
Transportation	111.0	0.7	1.0	19.5	11.7
Fuel Combustion and Stationary Sources	0.8	6.8	26.5	0.6	10.0
Industrial Processes	11.4	13.1	6.0	5.5	0.2
Solid Waste Disposal	7.2	1.4	0.1	2.0	0.4
Miscellaneous	16.8	3.4	0.3	7.1	0.4
Total	147.2	25.4	33.9	34.7	22.7
% Transportation	75	3	3	56	52

Reference: 3rd Annual Report on the Council on Environmental Quality", 1972.

C. Primary Pollutants

1. Emitted directly into atmosphere

2. Motor Vehicles

   a. CO
   b. HC
   c. NO_x
   d. Particulates (Pb, sulphates, rubber particles, asbestos fibers, etc.)

3. Stationary Sources

   a. HC
   b. NO_x
   c. SO_2
   d. Particulates

D. Secondary Pollutants

1. Caused by the chemical reaction of the mixture of primary pollutants in the atmosphere.

2. Ozone (O_3), peroxyacetyl nitrates (PAN) peroxybenzoyl nitrates (PBN)

III. Types of Smog

A. London Smog - reducing smog; SO_2
B. Los Angeles Smog - Photochemical Smog
C. Oregon Smog - waste burning
D. Ice Fog - temperature less than -25°F
E. See Figure 2-3

IV. Photochemical Smog

A. Grossly simplified equations

$$NO + O_2 \rightarrow NO_2$$
$$NO_2 + \quad = NO + O_+$$
$$O_+ + O_2 \rightarrow O_3$$
$$RHC + O_3 \rightarrow PAN$$

B. Formation of photochemical smog requires RHC and NO_x as well as ultraviolet light from the sun.

C. Reaction time requires 30 minutes to about 2-3 hours depending on emissions and meteorology.

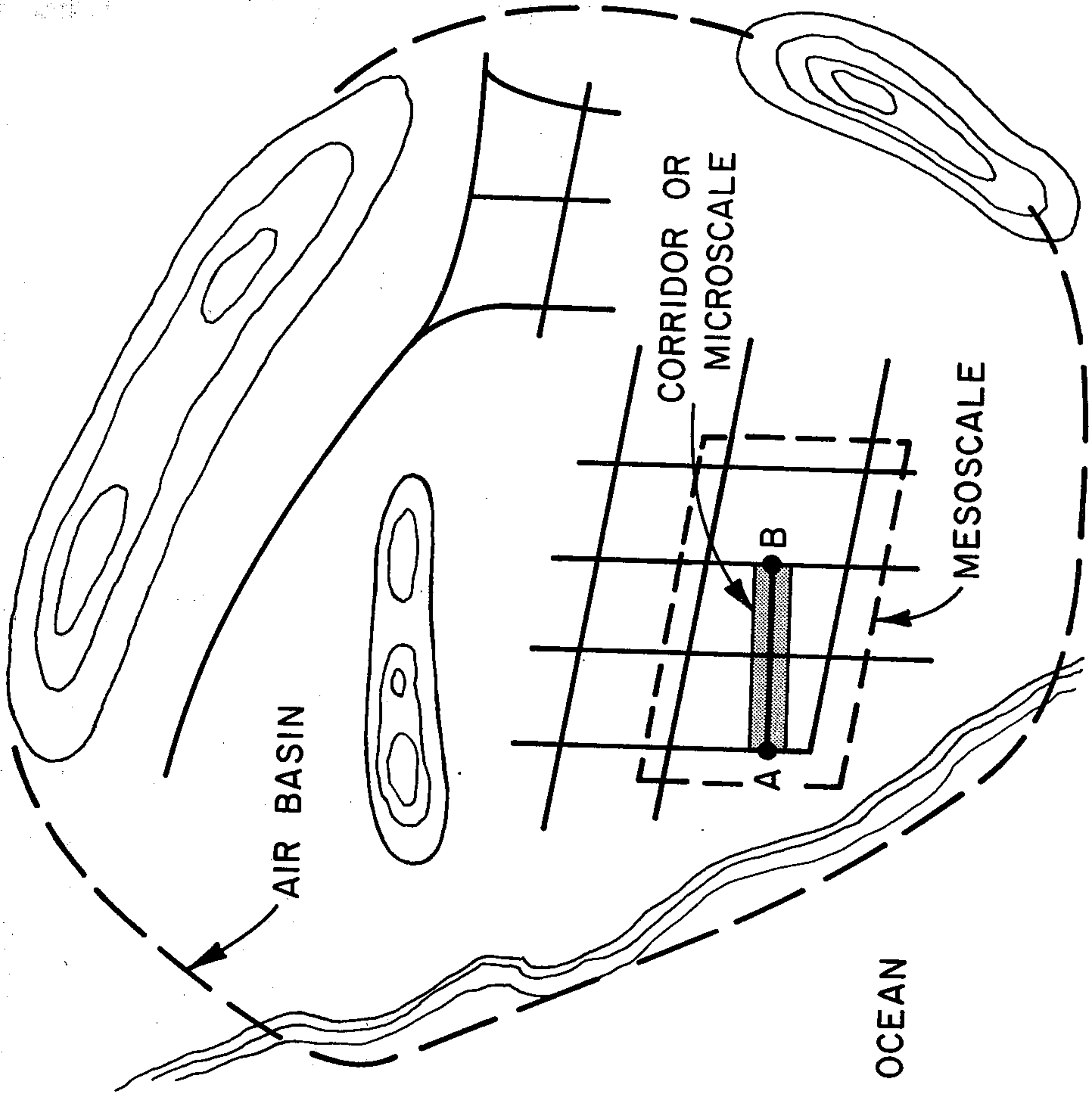


FIGURE 2-2

TYPE OF SMOG	METEOROLOGICAL CONDITIONS	MAIN FUEL	MAIN POLLUTANTS	COLOR
LONDON	COOL, MOIST WEATHER + INVERSION	COAL (SO_2)	H_2SO_4 + CARBON PARTICULATES	GRAY-BLACK
LOS ANGELES (PHOTOCHEMICAL)	WARM WEATHER AND SUNSHINE + INVERSION	GASOLINE USED IN AUTO.	O_3, PAN, PBN	YELLOWISH-BROWNISH
OREGON	———	BURNING FROM LUMBER MILLS & AGRICULT. WASTES	SMOKE & PARTICULATE MATTER	GRAY-BLACK
ICE FOG	STABLE ATMOSPHERIC CONDITIONS TEMP $<-25°$ F LIGHT WINDS	GASOLINE	CO	———

PAN = PEROXY – ACETYL NITRATE
PBN = PEROXY – BENZOYL NITRATE

FIGURE 2-3

V. Local Effects of Pollutant Emissions

A. Ozone depression near sources of NO

1. Reactions

NO	+	O_3	$\longrightarrow$	$NO_2 + O_2$
Vehicle emissions		Ambient levels		

2. Reduced ozone levels near roadways and increased NO_2 concentrations.

3. See Figure 2-4

B. Elevated Concentrations of CO, HC, NO_x

1. These pollutants are source oriented; the closer to the source the higher the concentrations.

2. See Figure 2-5

C. Air Monitoring Station Location

1. Relationship of Localized Effects on Air Quality if station located near sources of primary pollutants.

a. Point measurement is most representative of <u>microscale</u> air quality - High levels of CO, HC, NO_x, Low O_3 (ozone depression).

b. Point measurement is not representative of regional air quality.

OZONE DEPRESSION

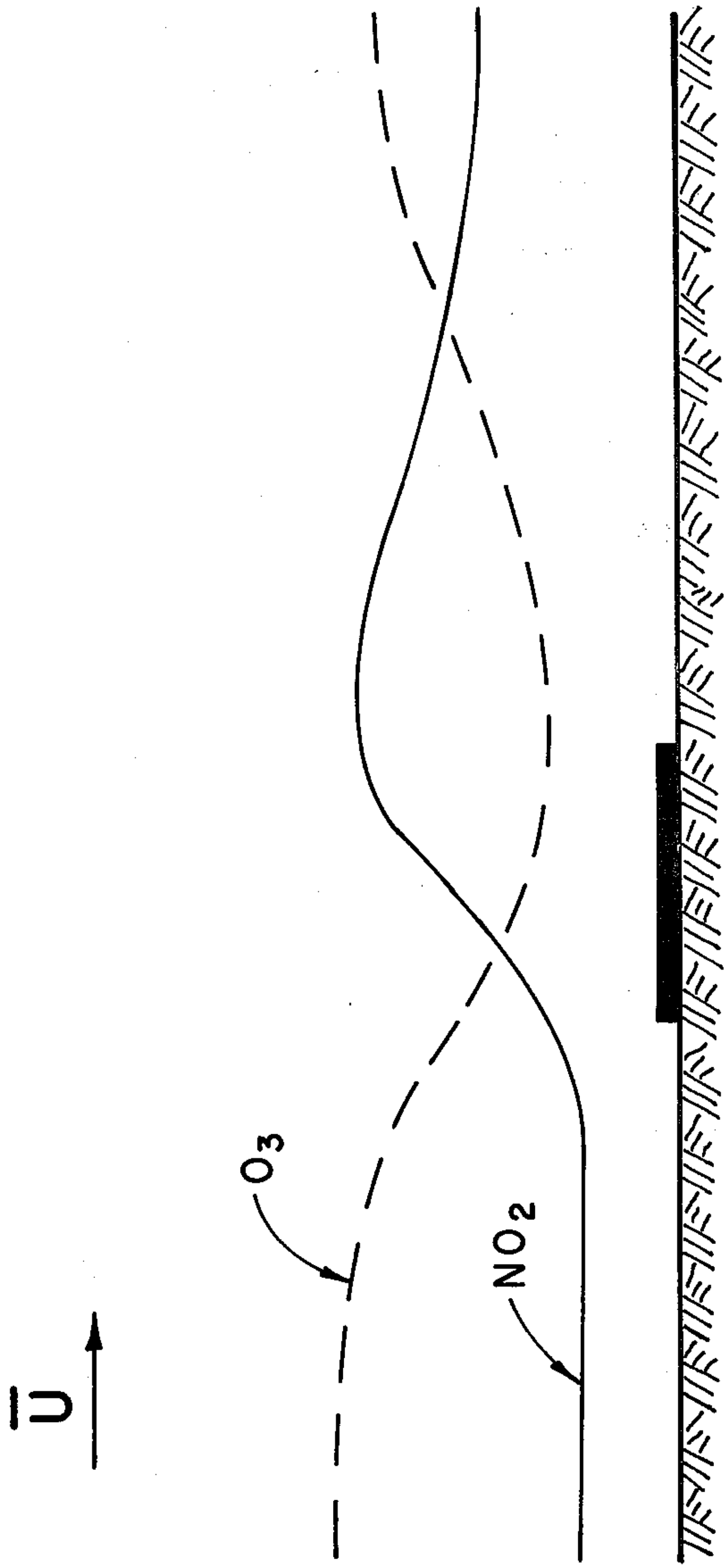


FIGURE 2-4

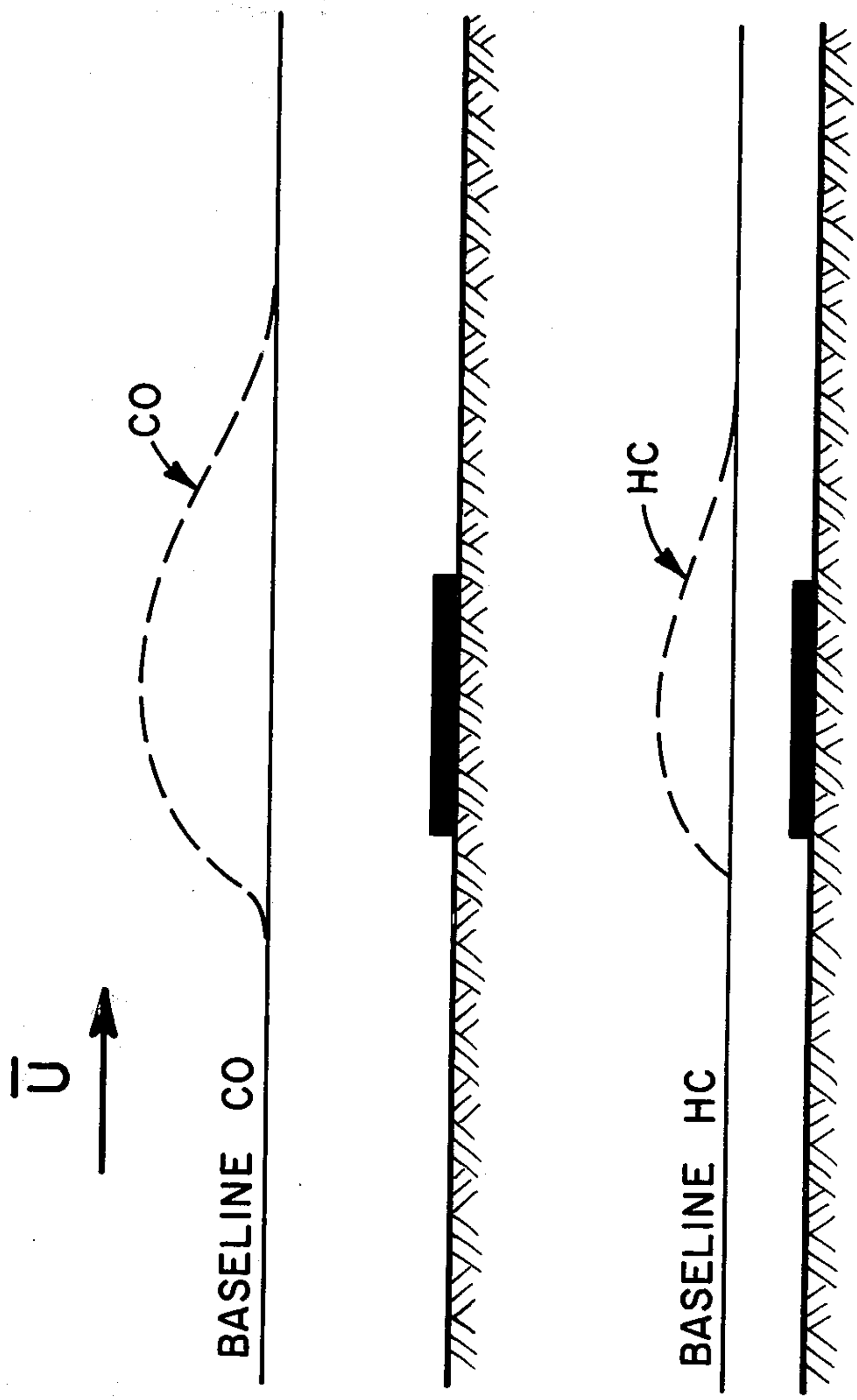


FIGURE 2-5

VII. Seasonal Trends in Air Quality

A. Primary Pollutants

1. Highest concentrations generally occur during late fall and winter during the night and early morning hours.

2. Lowest during summer.

B. Secondary Pollutants

1. Highest concentrations during summer

2. Lowest during winter

C. See Figure 2-6.

VIII. Health Effects of Air Pollution

A. Limited extent of information concerning the health effects of air pollution.

1. Difficult to measure
2. Difficult to quantify
3. Impact of air pollution on health is not well understood.

B. Diseases and Air Pollution

1. Respiratory diseases are generally associated with air pollution levels.

2. Bronchitis can be either acute (short term) or chronic (long term).

a. Inflammation of respiratory tract

b. Reversible

c. Breathing becomes more difficult

3. Emphysema, usually chronic

a. Alveoli become distended and uneven

b. Progressive destruction of alveoli

c. Decreased ability to eliminate foreign bodies

d. No known cure

C. Mechanisms of intake of air pollutants

1. Upper respiratory system

a. Nasal passages

b. Upper bronchial tubes

2. Lower respiratory system

a. Lower bronchial tubes

b. Alveoli

D. Defense mechanisms of the human lung

1. Defense against particulates

a. Nasal hairs

b. Curves in nasal passage

c. Impingement on walls of upper and lower respiratory tracts

d. Removal by expectoration from upper airway and cilia from walls of upper and lower airways

e. Particles of less than 5 μm penetrate into lower respiratory tract.

f. Particles 5 μm < radius < 1 μm are deposited immediately downstream of bronchial tree.

g. Particles 0.1 μm are deposited on respiratory tract, by diffusion due to brownian motion.

h. Particles 0.1 μm < radius < 1.0 μm are able to penetrate into the alveoli.

2. Defense against gaseous pollutants

a. Soluble gasses are chemically transformed in the upper airway.

b. If absorbed on particulates in size range 0.1 μm to 1.0 μm, soluble gasses can be carried to lower airway.

(1) SO_2 is an example

(2) Called synergistic effect

E. Health impact of suspended particulates

1. Particles > 1 μm are trapped in respiratory system by physical impaction

2. Particles < 0.1 μm are trapped in respiratory system by brownian motion

3. Remainder of particles penetrate into alveoli and cause damage

F. Health impact of carbon monoxide

1. Relatively insoluble in respiratory tract

2. Travels to alveoli where it enters bloodstream

   a. CO affinity 210X as fast as oxygen, O_2
   b. Produces carboxyhemoglobin
   c. Occupies space normally held by O_2
   d. Less "room" for O_2
   e. Remaining O_2 is retained more tightly by hemoglobin
   f. See Figure 2-7

G. Photochemical Oxidants

1. Primarily ozone
2. Relatively insoluble
3. Concentration $>$ 1 ppm produces narrowing of airways in the lungs
4. Prolonged exposure (chronic) to concentrations typically encountered in urban air (0.10 to 0.20 ppm) have not been demonstrated to be harmful.
5. It has been postulated that low levels of ozone may accelerate the aging process of lung tissue.
6. Athletes have shown a decreased ability to perform during elevated ozone levels.

H. Oxides of Nitrogen

1. No evidence of health hazards with nitric oxide
2. Nitrogen dioxide, being relatively insoluble, is known to irritate alveoli upon exposure to about 1 ppm for long periods of time.

I. Oxides of Sulfur

1. Sulfur dioxide is extremely soluble comapred to other pollutants.

2. In the absence of particulates, SO_2 forms sulfuric acid in the upper airway.

3. Particulate matter acts as a mechanism by which SO_2 penetrates to the alveoli and causes damage there.

IX. Lead

A. Correlations have been made between high atmospheric lead content and high blood lead content.

B. Heavy metals such as lead tend to accumulate in the body.

C. Poisoning by lead can damage the nervous system.

X. "Excess deaths" attributed to air pollution episodes:

Location	Date	Pollutants	Symptoms and effects
Meuse Valley, Belgium	1930	SO_2 (9.6-38.4 ppm)	63 excess deaths.
Donora, Pa.	1948	SO_2, particles (0.5-2 ppm)	20 excess deaths.
Poza Rica, Mexico	1950	H_2S	22 excess deaths.
London	1952	SO_2, particles	4000 excess deaths.
New York	1966	SO_2, particles	168 excess deaths

SEASONAL TRENDS IN AIR QUALITY

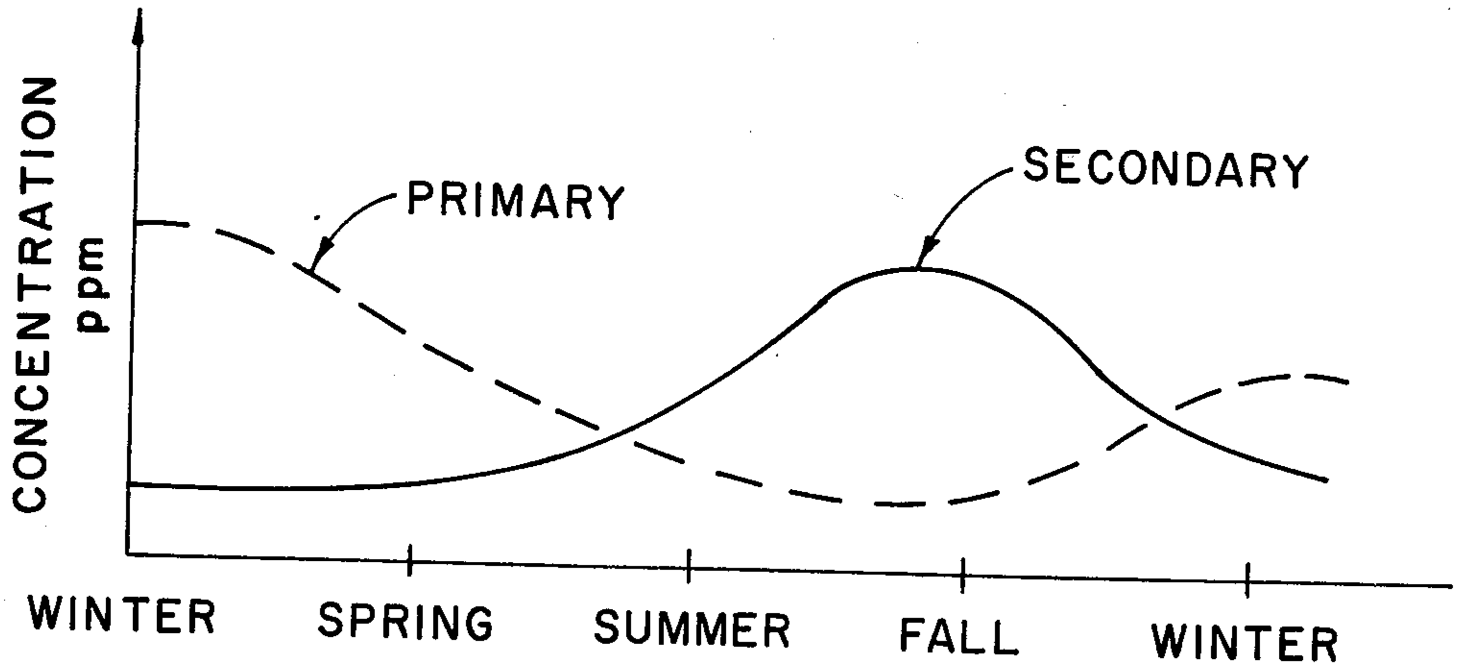


FIGURE 2-6

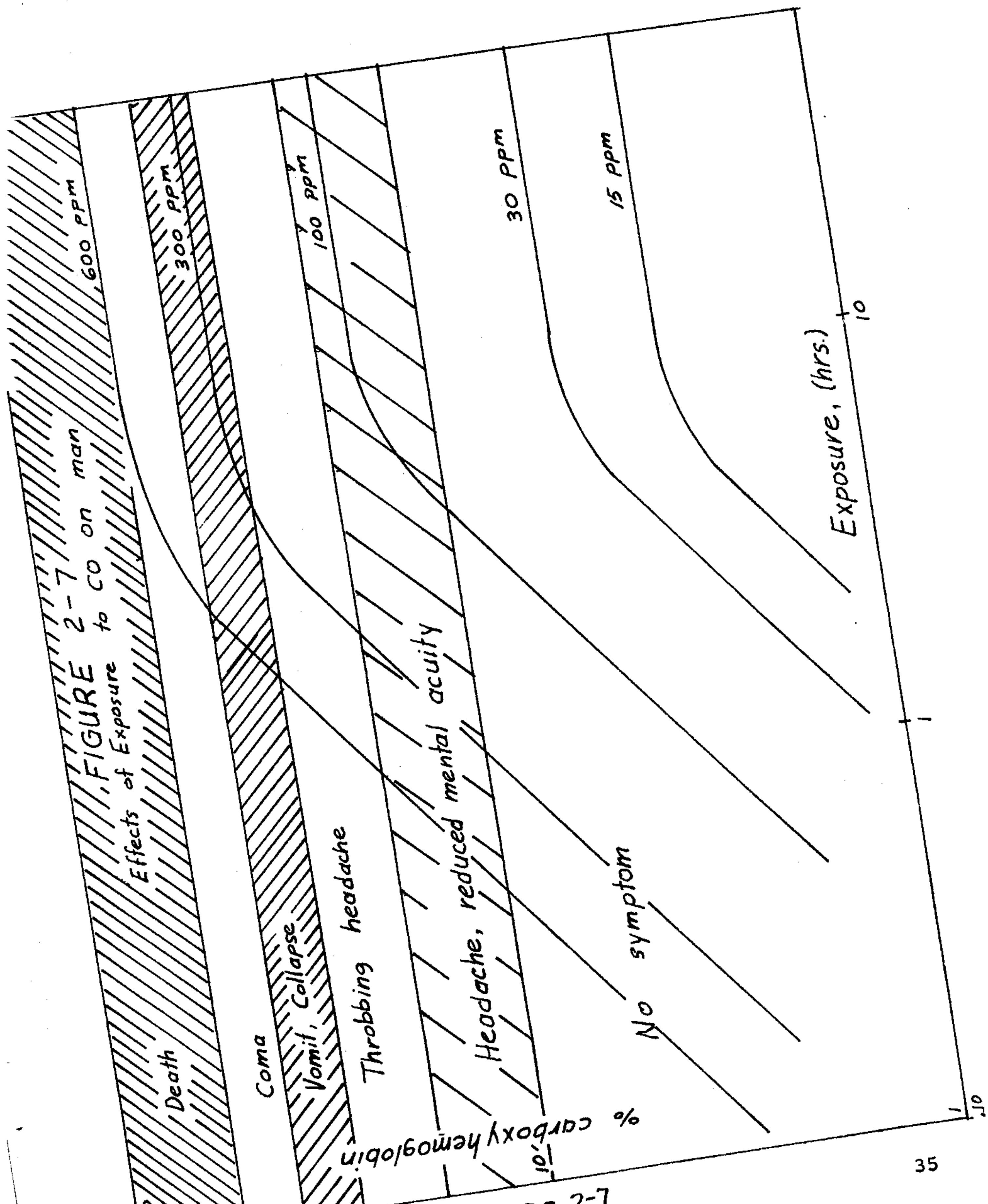


FIGURE 2-7
Effects of Exposure to CO on man
600 PPM
300 PPM
100 PPM
30 PPM
15 PPM
Death
Coma
Vomit, Collapse
Throbbing headache
Headache, reduced mental acuity
No symptom
% carboxy hemoglobin
100
10
10
1
10
Exposure, (hrs.)

FIGURE 2-7

XI. Air Pollution Effects on Vegetation

A. Definitions:

1. Injury - Something you can see that happens to a plant caused by air pollution

2. Damage - economic loss

3. Dose response - Time plant is exposed to a given concentration level of pollutants

a. Acute - high level, short time of exposure
b. Chronic - low level, long time exposure

4. Chlorosis - Loss of green color of plant or yellow areas

5. Necrosis - Death of plants

6. Stress - Any factor acting on a plant, i.e., light, temperature, nutrients, pH, soil, water, insects, etc.

7. Strain - Results from stress

B. Effects of Pollutants:

1. O_3 - Most sensitive varities (0.04 ppm O_3) are alfalfa, barley, tomato, grape, ponderosa pine.

2. NO_2 - Most sensitive are pinto beans, lettuce, tobacco.

3. SO_2 - Most sensitive are alfalfa, barley, soybean, ponderosa pine.

4. HC - In general are not harmful to plants except ethylenes and some olefins.

5. CO - Little is known about the effects on vegetation.

References:

1. Recognition of Air Pollution Injury to Vegetation: Edited by J. S. Jacobson and A. Clyde Hill, Air Pollution Control Association, 1970.

2. EPA Training Course: Air Pollution Effects on Vegetation, Research Triangle Park, North Carolina, 1974.

XII. Pollutants Considered in Transportation Air Quality Studies

A. Pollutants of Major Concern:

Pollutant	Microscale	Mesoscale	Macroscale
CO	Yes	Yes	Yes
HC	No*	"	"
NO_x (NO_2)	"**	"	"
Particulates	"***	"	"***
O_3	No	"	"
Sulphates	"****	"	"

*No direct health effect from HC

**No validated models available to treat the chemical reactions of NO and O_3. Also there are no emission factors available from either EPA or ARB of NO_2.

***No emission factor of Pb as a function of speed from either EPA or ARB.

****Under investigation by EPA to evaluate the health effects.

B. For transportation Impact Studies based on available data:

Pollutant	Microscale	Mesoscale	Macroscale
CO	Yes	Yes	Yes
HC	No	Yes	Yes
NO_x	No	Yes	Yes
Particulates	No	No	No
O_3	No	Yes	Yes
Sulphates	No	No	No

XIII. Air Quality Predictions

A. Transportation Alternatives

1. No Build Alternative

2. Planning Alternatives

a. Spatial alternatives
b. Modal alternatives
c. Temporal alternatives

3. Design Alternatives

a. Geometry
b. Capacity
c. Flow

B. Forecast Years

1. Present or baseline
2. Estimated Time of Completion (ETC)
3. ETC+10 years
4. ETC+20 years design year (long term)

C. Meteorology

1. Typical day
2. Bad day

D. Slides on Air Pollution

SECTION 3

TRAFFIC REQUIREMENTS FOR TRANSPORTATION IMPACT STUDIES

I. Purpose of this Section

A. Discuss the interface of transportation simulation models and air quality models.

B. Outputs of transportation models.

C. Problem and limitations of transportation simulation models

II. Traffic Information is required for impact analysis for the following reasons:

A. Main driving force in all microscale and regional air quality models.

B. Land use patterns reflect traffic generation.

C. Growth of communities reflects the transportation plan or system.

D. To evaluate the effects of mass transit in terms of air quality impact.

E. To evaluate energy requirements of different modes of transportation.

F. FHWA requires an evaluation of the transportation plan as specified in FAHPM 7-7-9.

G. To determine the inter-relationships of land use, transportation and air quality planning.

III. Traffic forcasting is the Most Difficult Task in the Air Quality Analysis

A. This course develops the procedures and methods for the following:

1. Emission Factors
2. Meteorological Data and Analysis
3. Air Quality Data and Analysis
4. Air Quality Modeling

5. Environmental Planner will have complete control in the design and analysis of the above items. However, traffic analysis is made by transportation planners and engineers.

B. This Section discusses the traffic information required for an environmental evaluation and not the technical procedures of transportation simulation modeling. For the technical details of traffic forecasts, the services and expertise of transportation planners and engineers is essential.

C. Overview of Transportation Simulation Models

Trip Generation Model
Modal Split Model
Distribution Model

↓

Outputs For
Environmental Assessment

IV. Time Periods for Traffic Information

A. Present

B. ETC

C. ETC+10 years

D. ETC+20 years

E. See Figure 3-1

V. Transportation Alternatives

A. No build - yardstick

B. Planning Alternatives

1. Spatial - Location
2. Modal - Bus, Rail, Auto
3. Temporal - Scheduling

C. Design Alternatives

1. Geometry - Grade, median, cross-section
2. Capacity - Volumes, stage construction
3. Flow - V/C Ratio, Ramp Control

D. See Figures 3-2, 3-3, 3-4 and 3-5

VI. Meteorology

A. Typical and bad day for:

1. Summer O_3
2. Winter, CO, HC, NO_2

B. See Figure 3-6

FORECAST PERIODS
FOR TRANSPORTATION IMPACT ASSESSMENT

I PRESENT OR BASELINE YEAR, FRAME OF REFERENCE.
PREDICT FUTURE TRENDS.

II ETC = ESTIMATED TIME OF COMPLETION.

III ETC + 10 YRS, EPA INDIRECT SOURCE REGULATIONS.

IV ETC + 20 YRS, DESIGN YEAR.

FIGURE 3 - 1

TRANSPORTATION ALTERNATIVES

1. NO BUILD.
2. PLANNING.
   - A. SPATIAL
   - B. MODE
   - C. TEMPORAL
3. DESIGN.
   - A. GEOMETRY
   - B. CAPACITY
   - C. FLOW

Figure 3-2

TRANSPORTATION ALTERNATIVES

I NO BUILT-YARD STICK OR BASELINE FOR COMPARISON.

II PLANNING

- A. FREEWAYS
- B. ARTERIALS
- C. TRAFFIC ENGINEERING IMPROVEMENTS.
  1. TRUCK LANES.
  2. WIDENING.
  3. IMPROVE TRAFFIC FLOW, CONTROLLED RAMPS, TURN LANES, SIGNALIZED INTERCHANGES.

FIGURE 3-3

TRANSPORTATION ALTERNATIVES (CONT.)

D - TRANSIT MODES AND TERMINAL FACILITIES

1. BUSWAYS (EXPRESS TRANSIT)
2. EXCLUSIVE BUS LANES (SURFACE TRANSIT)
3. FIXED RAIL.
4. RAPID TRANSIT.
5. COMMUTER RAILROADS.
6. PERSONAL RAPID TRANSIT.
7. CENTRAL BUSINESS DISTRICT PARKING FACILITIES.
8. FRINGE AREA OF CBD PARKING FACILITIES.
9. TRANSIT STATION PARKING.

FIGURE 3-4

TRANSPORTATION ALTERNATIVES (CONT.)

E - TEMPORAL COMBINATIONS OF A THRU D OR POSSIBLE STAGING OF CONSTRUCTION TO REDUCE AIR POLLUTION.

F - ENERGY REQUIREMENTS.
  a) PASSENGER MILE PER MODE OF TRAVEL.
  b) PASSENGER PER MODE OF TRAVEL.

Figure 3-5

APPLICATIONS OF AIR QUALITY MODELS

I TYPICAL OR MOST PROBABLE METEOROLOGICAL CONDITIONS.

1 WINTER, PRIMARY POLLUTANTS (CO, HC, NO_x)

2. SUMMER, SECONDARY POLLUTANTS (O_3)

II BAD OR WORST METEOROLOGICAL CONDITIONS.

1 WINTER.

2 SUMMER.

III COMBINATIONS OF METEOROLOGY AND TRAFFIC.

1. TYPICAL DAY.

2. WORST DAY.

FIGURE 3-6

VII. Detailed Traffic Information

A. See Figures 3 to 17 in Traffic Manual.

VIII. Considerations of Mass Transportation

A. Must be a completely integrated system; rail, buses, etc; must provide facilities to allow people to take all modes.

B. Energy requirements for mass transit and highway alternatives must be evaluated.

C. Must provide transportation during peak morning and evening rush hours. If provisions are not given for these periods it may possibly double peak volumes on number of trips to and from stations.

D. Family members have car to make additional shopping trips, etc.

E. What is the temperament in the community for the development of mass transit? Highways?

F. Demand traffic simulation models must be changed to provide a model that can analyze mass transportation impacts.

IX. Problems and Difficulties in Obtaining Traffic Information

A. Define mesoscale region - Route 105 in Los Angeles. Courts decided the study area.

B. Speeds on each link

1. Typically 25 mph city and 60 mph on freeways or just posted limits.

C. No build alternative

1. Route 580 - FHWA did not approve report until no build was considered.

D. Alternatives - especially mass transit

1. Route 580 - No one knew when BART systems would be constructed or what effect it would have on traffic patterns.

2. Environmental groups review air quality reports as "chewing up EIS because it considers moving vehicles and <u>not</u> <u>people</u>".

E. Growth Factors - must be changed to reflect the existing trends of land use and development.

1. Los Angeles growth in 1950, 1960, 1970 and LARTS Model.

F. Time to complete traffic studies - time varies from 6 months to 2 years.

1. Bay Area $130/month to air quality consultant for delay.

2. Route 105 approximately 2 years.

G. Traffic Models have no capacity constraints.

H. Effects of energy crisis on increase gasoline prices - reduced number of trips.

I. Demand Models are not flexible at present to answer todays questions concerning environmental impacts of alternatives and control strategies.

Before requesting any traffic information have a meeting involving (1) transportation planners, (2) environmental planners, and (3) local planning commissions and agencies. This cooperative effort will save time and effort and provide information that is creditable.

X. Introduction to Transportation System Analysis

A. Land use

B. Traffic

C. Air Quality

D. See Figures 3-7 through 3-13

XI. Examples of Traffic Requirements

A. See Figures 3-14 and 3-15.

KEY FACTORS, ASSUMPTIONS AND POLICIES AFFECTING AIR QUALITY

LAND USE

TRAVEL

EMISSIONS &
CONCENTRATIONS

FIGURE 3-7

GROWTH

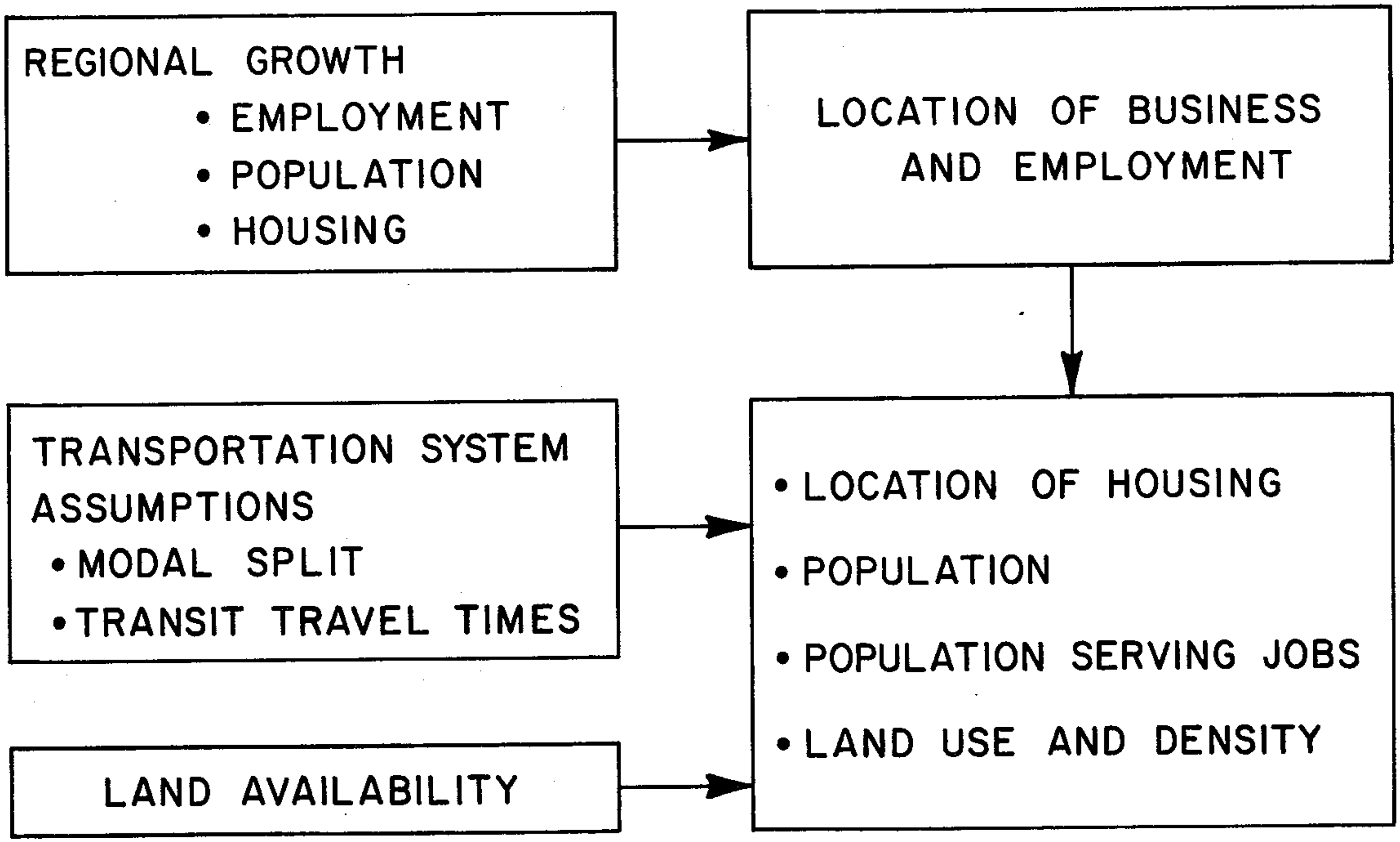


FIGURE 3-8

GROWTH

TOTAL GROWTH

- ECONOMIC STRENGTH OF REGION
- BIRTH RATE

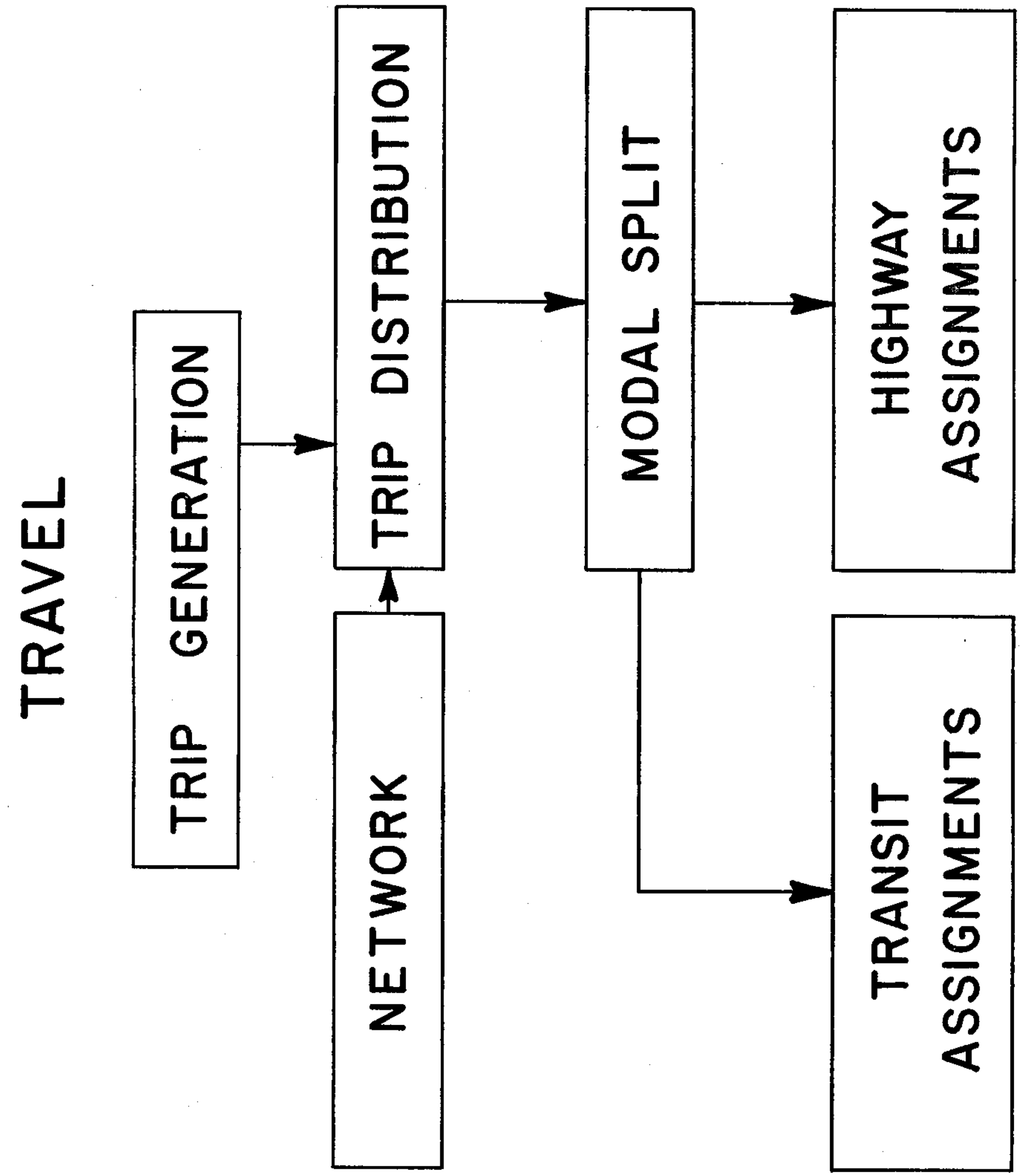
LOCATION OF GROWTH

- RELATIVE TO WIND TRAJECTORIES

DENSITY OR CLUSTER OF GROWTH

- COMPATABILITY OF TRANSIT

FIGURE 3-9



TRAVEL
TRIP GENERATION
TRIP DISTRIBUTION
NETWORK
MODAL SPLIT
HIGHWAY ASSIGNMENTS
TRANSIT ASSIGNMENTS

FIGURE 3-10

TRAVEL

TRIP MAKING

- NUMBER OF TRIPS PER PERSON
- AUTO AVAILABILITY
- VEHICLE OCCUPANCY
- CAR POOLING
- LENGTH OF TRIP & TIME OF DAY

SYSTEM CHARACTERISTICS

- CAPACITY
- CONGESTION & BOTTLENECKS
- SPEED
- PARKING AVAILABILITY
- TRAVEL COSTS & TOLLS

MODAL CHOICES

- ATITUDE OF PREFERENCES
- LEVEL OF SERVICE, CONVENIENCE
- RELATIVE TRAVEL TIME & COST

ENERGY

- SUPPLY
- PRICE

FIGURE 3 - 11

EMISSIONS & CONCENTRATIONS

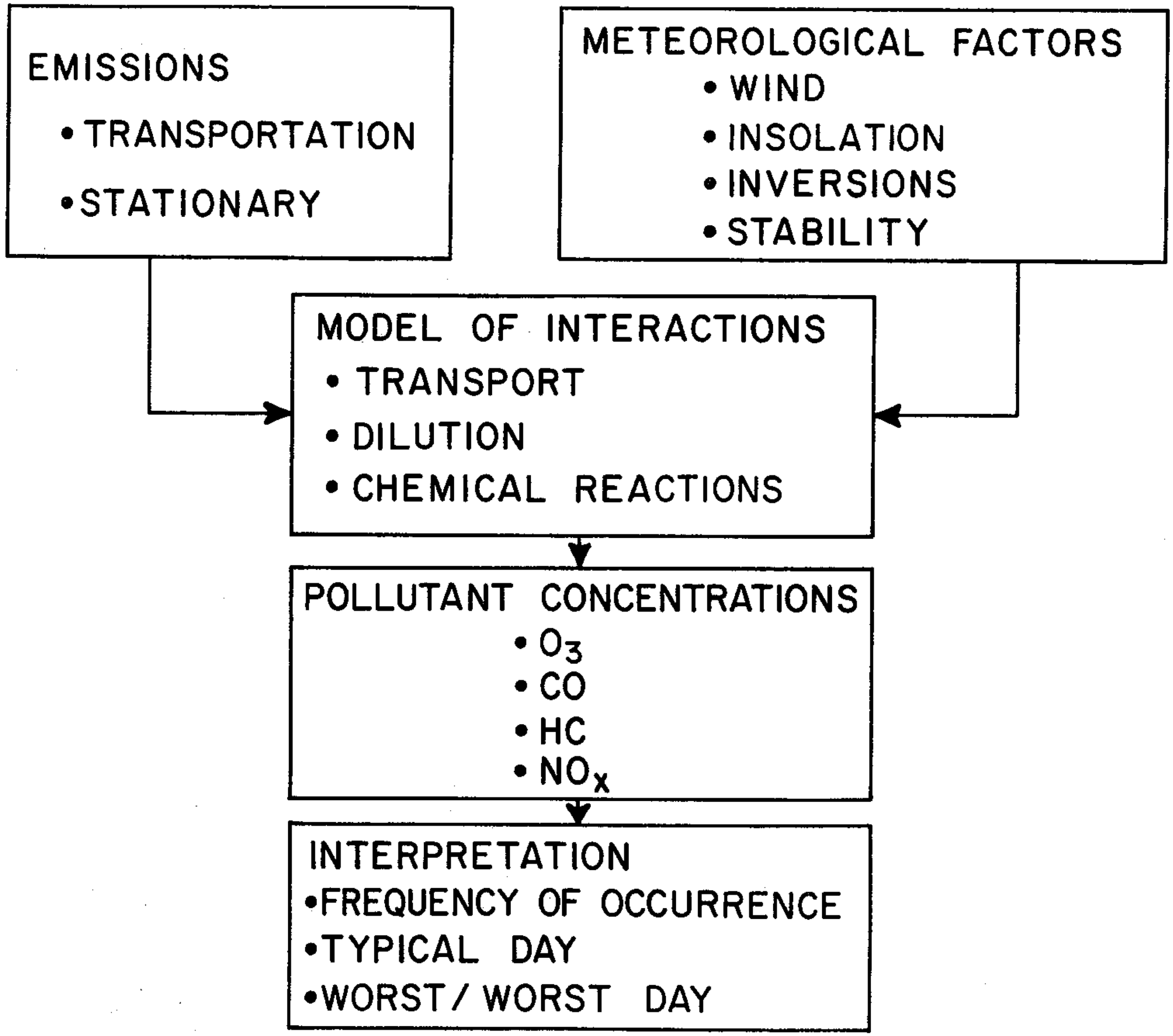


FIGURE 3-12

EMISSIONS & CONCENTRATIONS

EMISSION CHARACTERISTICS OF VEHICLES

- TYPE OF VEHICLES
- COLD START EMISSION
- HOT START EMISSION
- ENGINE DESIGN - CONTROLLED VS UNCONTROLLED

LOCATION OF EMISSIONS

- TRANSPORTATION
- STATIONARY

TIME OF EMISSIONS

- TRANSPORTATION
- STATIONARY

METEOROLOGICAL CONDITIONS

- RELATED TO SMOG
- PREDICTABILITY

CONCENTRATIONS AS A FUNCTION OF EMISSIONS

- AIR QUALITY STANDARDS
- WORST AND TYPICAL CASE
- PROBABILITY

FIGURE 3-13

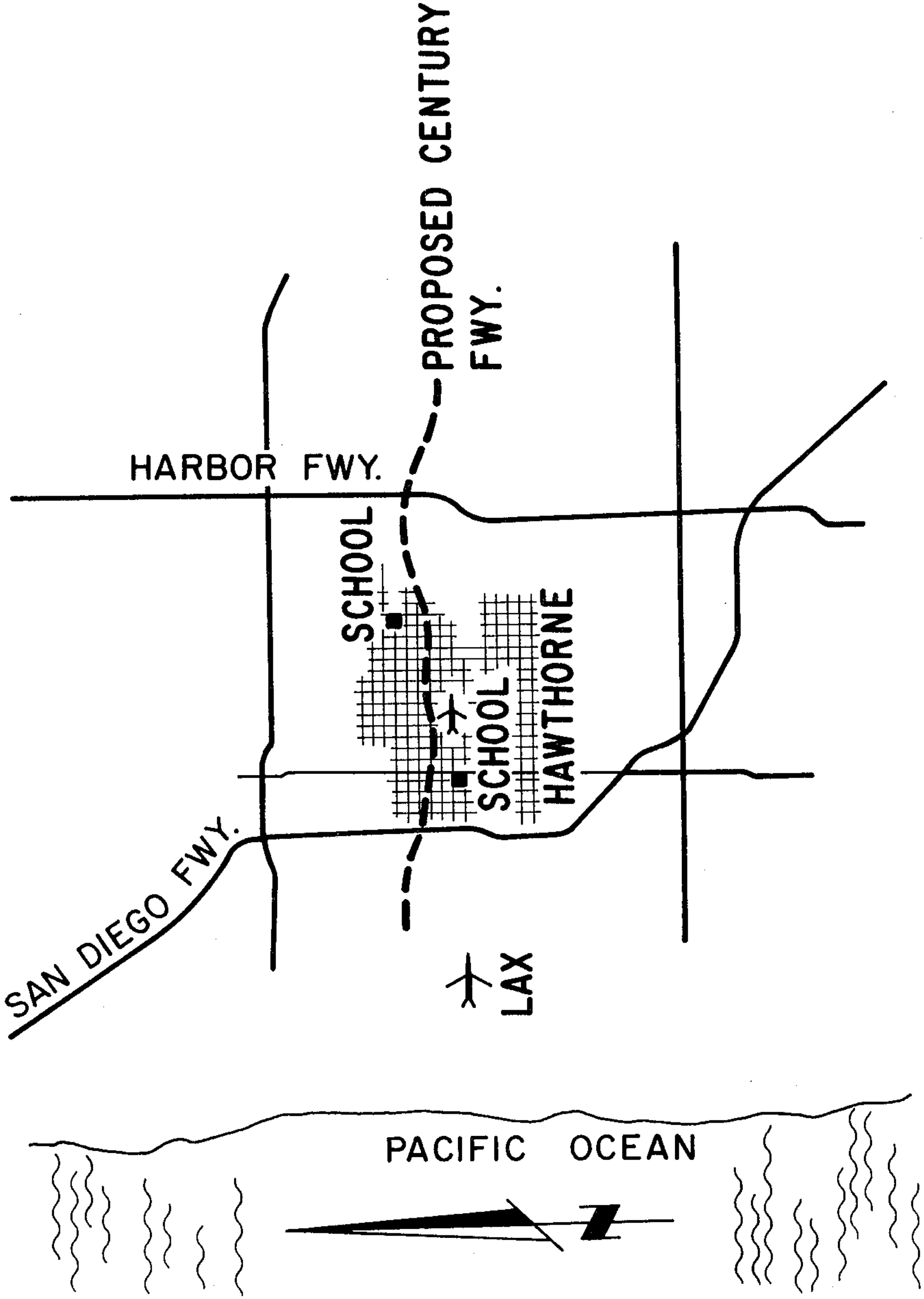

PROPOSED CENTURY FWY.
HARBOR FWY.
SCHOOL
SCHOOL
HAWTHORNE
SAN DIEGO FWY.
LAX
PACIFIC OCEAN

FIGURE 3-14

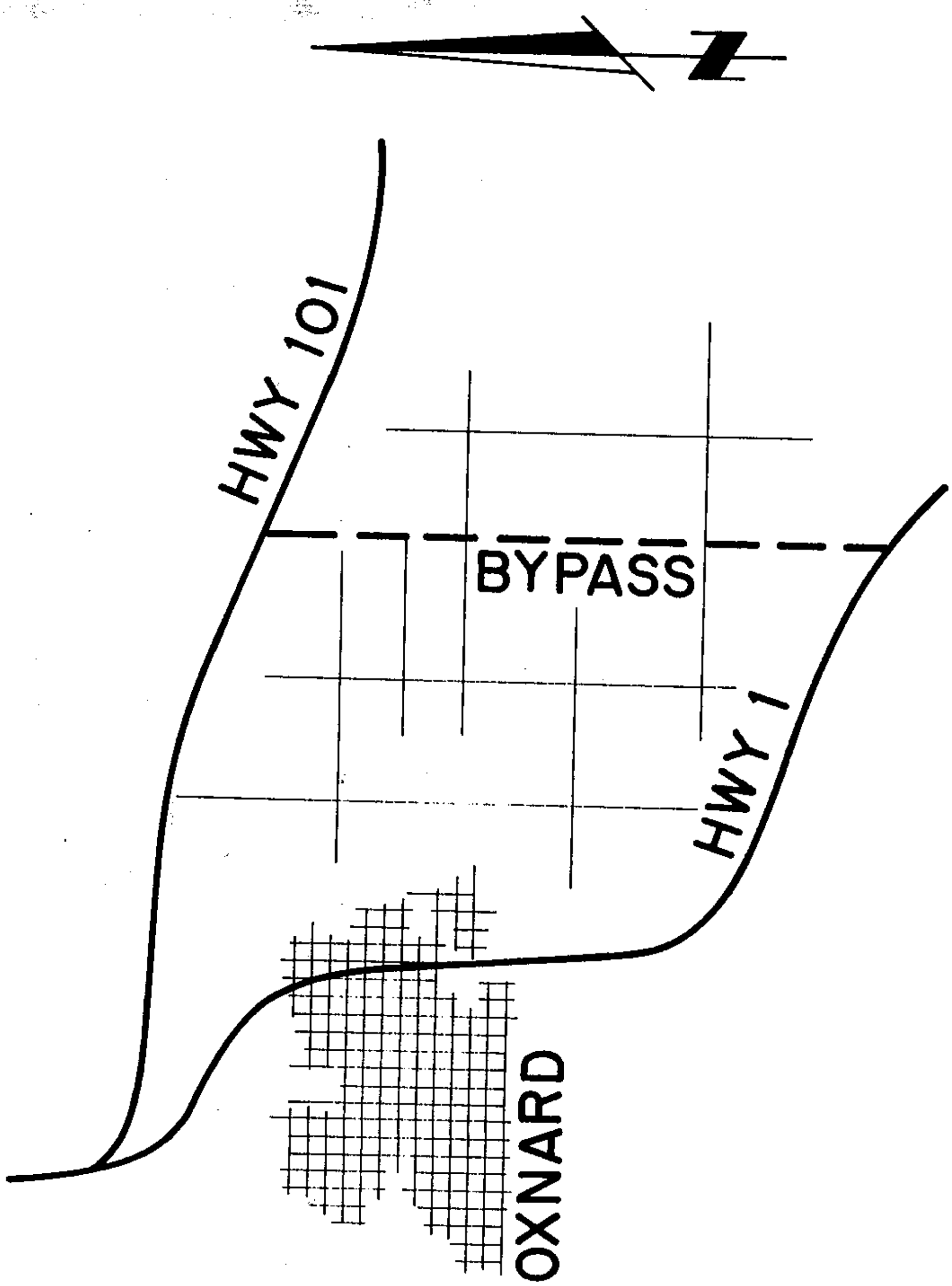


FIGURE 3-15

SECTION 4

EMISSION FACTORS FOR MOTOR VEHICLES

I. Definition of Emission Factor: A figure which represents the quantity of pollutant emitted from a source per unit time or per unit distance. This factor is used to multiply the traffic volumes or miles traveled over a specific time period to estimate pollutant emissions.

II. Units of Emission Factors

A. Modal (idle, cruise, acceleration, etc) = gms/sec or gms per unit time

B. Trip = gms/mi

C. Separate emission factor for each pollutant CO, HC, NO_x, and others as they become available.

III. Factors Affecting Emission Factor for a Single Vehicle

A. Vehicle model year - control standards vary.
B. Vehicle operating mode - cruise, accelerate, etc.
C. Condition of devices - maintenance
D. Engine condition - maintenance
E. Cold or warm start
F. Type of vehicle - LDV, HDV, diesel, etc.

IV. Ideal Emission Factors

A. Trip description

B. Summation of operating times in various modes

C. Multiplication by appropriate modal emission factor

D. Summation of total emissions

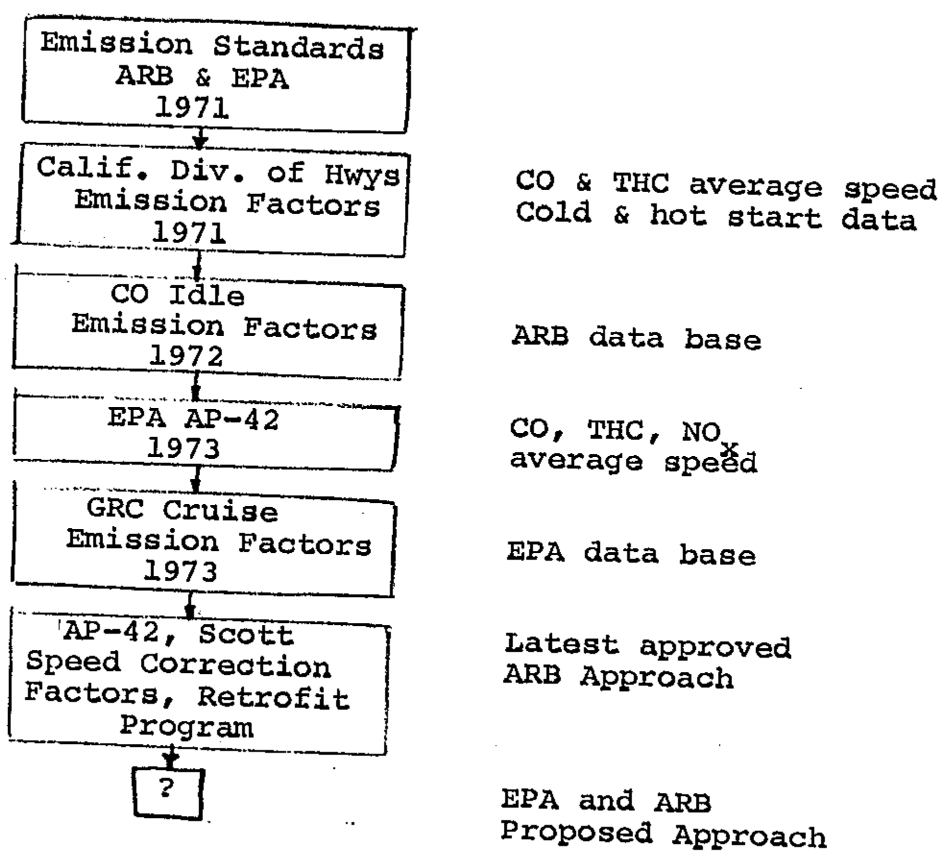
E. Adjust for:

1. milage per model year
2. modal mix
3. control deterioration

F. Repeat for each car on the road

G. See Figure 4-1

V. Chronological Development of Emission Factors



VI. Available Data for Calculating Emission Factors

A. California 7 - mode test cycle

B. Federal Test Procedure

C. CVS - 1 - See Figure 4-2

D. CVS - 2 - See Figure 4-2

E. AP-42

"IDEALIZED" EMISSION FACTORS

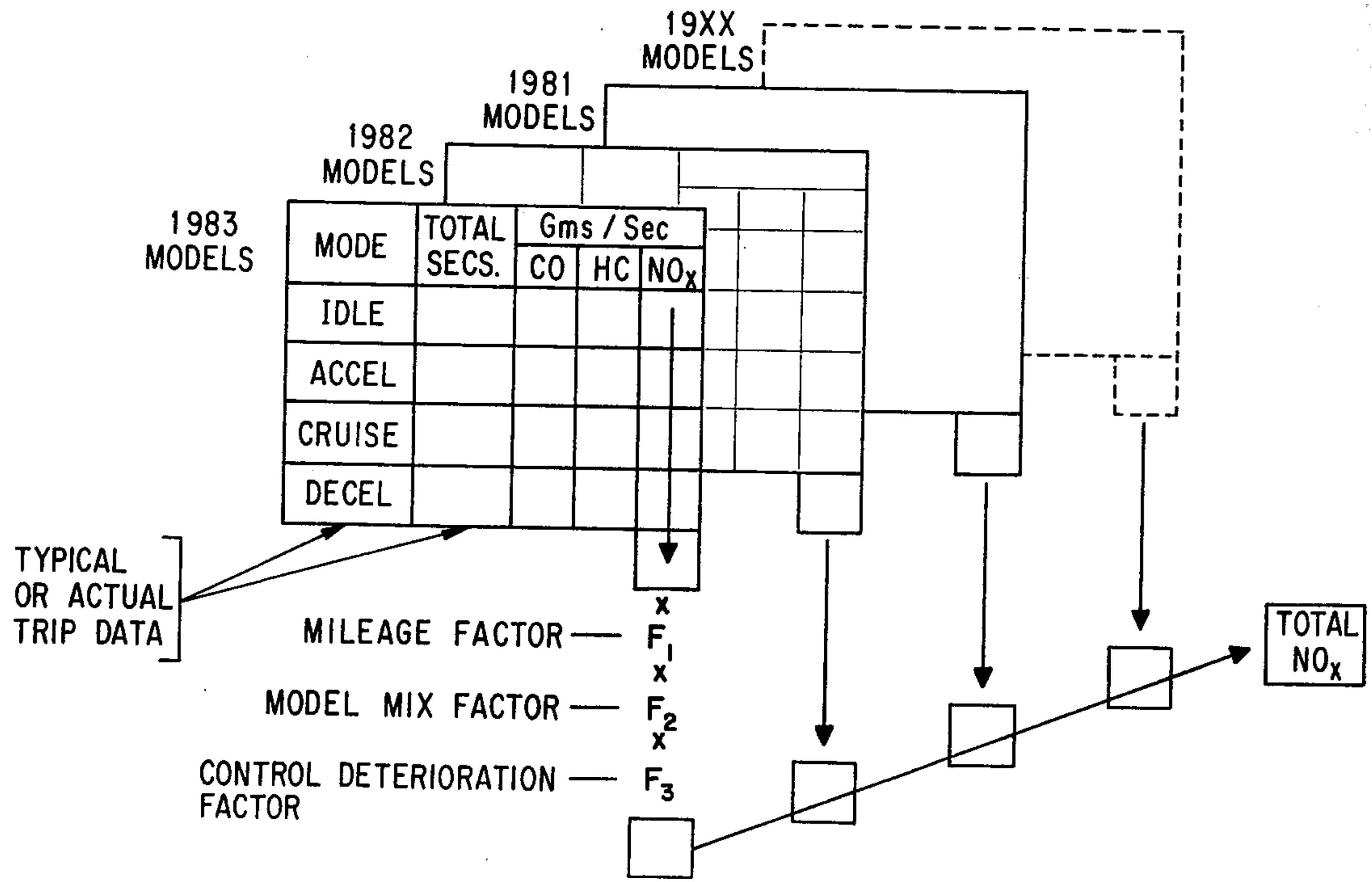


FIGURE A-1

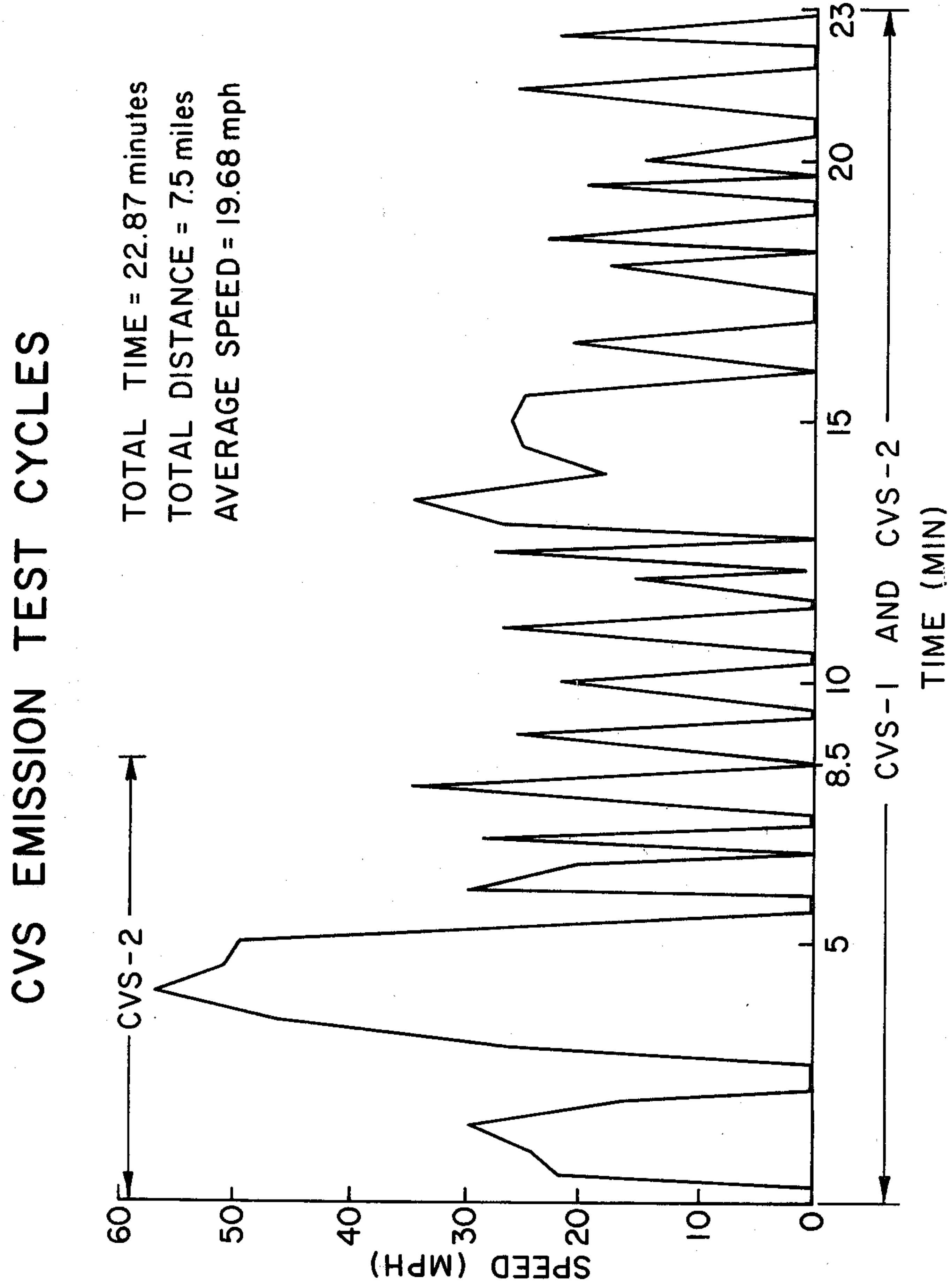

CVS EMISSION TEST CYCLES
TOTAL TIME = 22.87 minutes
TOTAL DISTANCE = 7.5 miles
AVERAGE SPEED = 19.68 mph
CVS-2
CVS-1 AND CVS-2
CVS-2
TIME (MIN)
SPEED (MPH)
0
10
20
30
40
50
60
5
8.5
10
15
20
23

FIGURE 4-2

AIR QUALITY MANUAL MODIFICATION

Prepared by

Michael Batham
Transportation Laboratory
September 18, 1974

Revised Modification No. 3 and 4 - Revision of Existing Emission Factors Based Upon EPA Manual AP-42 (April 1973), Scott Research Report SRL 2148-07-0274 (February 11, 1974) and the latest vehicle mix distribution from ARB.

The new emission factors are based on (1) a recent 1,000 vehicle study made by the Environmental Protection Agency and reported in their Manual AP-42 entitled, "Compilation of Air Pollutant Emission Factors", and (2) Scott Research Laboratory Report SRL 2148-07-0274 entitled "Driving Patterns at Various Average Route Speeds". These two reports, along with recent data from the California Air Resources Board, incorporated the latest available information such as new speed correction equations, the latest vehicle population distribution, emissions from heavy duty diesel powered vehicles, the interim California Emission Standards, and the 1966 to 1970 Vehicle Retrofit Program.

The data used in calculating these emission factors are based on current technology and existing emission standards. Because of this, changes in such things as: the emission standards, retrofit requirements, shift to smaller cars, and new emission test data will cause these emission factors to be modified. When these changes are made, the emission factors will be updated and the modifications will be forwarded to the districts.

These new factors will replace Air Quality Manual Modification No. 2 (October 10, 1973) currently in use. The emission factors are listed on the Tenet Time-Share Computer and can be accessed by linking '5;LAB;EMFAC'. This program will calculate total or reactive hydrocarbons, oxides of nitrogen, and carbon monoxide emission factors for any mix of light and heavy duty vehicles at average speeds from 10 to 60 mph based on the following mathematical equations:

$$enp = \sum_{i=n-10}^{n+1} c_{ip} \; d_{ipn} \; m_{in} \; s_{ip}$$

where enp = exhaust emission factor in grams per vehicle mile for calendar year n and pollutant p,

c_{ip} = the 1975 Federal test procedure emission rate for pollutant p (grams/mile) for the i^{th} model year, at low mileage. (table 1 thru 4). These low mileage emission rates are different from the new vehicle emission standards (tables 13 & 14) because the new vehicle standards are based on 50,000 miles of vehicle operation.

d_{ipn} = the controlled vehicle pollutant p emission deterioration factor for the i^{th} model year at calendar year n (tables 5 thru 8).

m_{in} = the weighted annual travel of the i^{th} model year during calendar year n (the determination of this variable involves the use of the vehicle model year distribution). (tables 9 thru 12).

s_{ip} = the weighted speed adjustment factor for exhaust emission for pollutant p for the i^{th} model year vehicles. (Figures 1 thru 5).

In addition to exhaust emission factors, the calculation of hydrocarbon gasoline motor vehicle emissions involves evaporative and crankcase hydrocarbon emission rates. Evaporation and crankcase emissions can be determined using:

$$fn = \sum_{i=n-10}^{n+1} h_i \; m_{in}$$

where,

fn = the combined evaporative and crankcase hydrocarbon emission factor for calendar year n,

h_i = the combined evaporative and crankcase emission rate for the i^{th} model year (tables 1 thru 4).

m_{in} = the weighted annual travel of the i^{th} model year during calendar year n (tables 7 thru 10).

The pollutant emission rates (C_{ip}) are based on the vehicle emission standards as published in 1973 and were obtained from AP-42. (See tables 1 thru 4). The emission rates for the interim emission standards and the new emission standards for the 1975-76 light duty trucks, which became law after AP-42 was published, were derived by ratioing the new and the old standards times the old emission rates.

The emission deterioration factors (d_{ipn}), as published in AP-42, were expanded to include the new and interim emission standards (see tables 5 thru 8).

The distribution of vehicle miles traveled by model year (M_{in})

was obtained from ARB and is based on 1973 vehicle population statistics from the California Department of Motor Vehicles (See tables 9 thru12). This distribution considers light duty passenger cars, light duty trucks, heavy duty gasoline vehicles and heavy duty diesel vehicles.

The speed correction factors (S_{ip}) are based on a series of equations derived from EPA by the Scott Research Laboratory (report mentioned earlier)(see figures 1 thru 5). This report lists a different speed correction equation for each major automotive pollutant and for all vehicle model years tested (pre 1966 thru 1971, light duty only). The heavy duty vehicles, both gasoline and diesel, are assumed to have the same speed correction factors as the light duty vehicles. These speed correction factors replace those listed in AP-42.

These emission factors as listed on the Tenet computer system also take into consideration the Retrofit Emission Control Program for 1966 thru 1970 model year vehicles in the appropriate counties. This Retrofit Program will go into effect during late 1974 and early 1975. The program asks the user if the project is within the six counties (Los Angeles, Ventura, Orange, Santa Barbara, San Bernardino, or Riverside) where this retrofit program is required. If the user responds yes, each yearly printout sheet will state "Project is within the 1966-70 RETROFIT AREA". If the user responds no, as would be the case in all the other counties, the retrofit portion of the calculations will be excluded.

The Retrofit Program for 1955 thru 1965 vehicles was not included in this program because the vehicle miles traveled by these vehicles only amount to approximately 5% of the total miles traveled today. This percentage will be even less in future years.

If the user of this program is making estimates of oxidant concentration using the roll-back technique, he should use the reactive hydrocarbon option as listed in the beginning of the program. This option assumes 75% of exhaust hydrocarbons and 67% of the evaporative and crankcase hydrocarbons are reactive. These percentages were obtained from ARB.

Attached is a copy of the new emission factor program including the data files listing the various factors. It is important to note all of the assumptions and changes made in this Emission Factor program were made with the verbal approval of Don Braton and Terry McGuire of the Air Resources Board.

TABLE I

EMISSION RATES FOR LIGHT DUTY VEHICLES
Below 3500 Feet in Elevation

Model Year	Passenger Cars CO	Passenger Cars NO_x	Passenger Cars Exhaust HC	Passenger Cars Evaporative HC	Light Duty Trucks CO	Light Duty Trucks NO_x	Light Duty Trucks Exhaust HC	Light Duty Trucks Evaporative HC
1960	87	3.6	8.8	7.1	87	3.6	8.8	7.1
1961	87	3.6	8.8	3.8	87	3.6	8.8	3.8
1962	87	3.6	8.8	8.8	87	3.6	8.8	3.8
1963	87	3.6	8.8	3.8	87	3.6	8.8	3.8
1964	87	3.6	8.8	3.0	87	3.6	8.8	3.0
1965	87	3.6	8.8	3.0	87	3.6	8.8	3.0
1966	51	3.4	6.0	3.0	51	3.4	6.0	3.0
1967	50	3.4	4.6	3.0	50	3.4	4.6	3.0
1968	46	4.3	4.5	3.0	46	4.3	4.5	3.0
1969	39	5.5	4.4	3.0	39	5.5	4.4	3.0
1970	36	5.1	3.6	0.5	36	5.1	3.6	0.5
1971	34	3.5	2.9	0.5	34	3.5	2.9	0.5
1972	19	3.5	2.7	0.2	19	3.5	2.7	0.2
1973	19	2.3	2.7	0.2	19	2.3	2.7	0.2
1974	19	2.3	2.7	0.2	19	2.3	2.7	0.2
1975	4.8	1.5	0.5	0.2	10.6	1.5	1.1	0.2
1976	4.8	1.5	0.5	0.2	9.0	1.5	0.5	0.2
1977	1.8	1.5	0.23	0.2	9.0	1.5	0.5	0.2
1978	1.8	0.31	0.23	0.2	9.0	1.5	0.5	0.2

TABLE 2

EMISSION RATES FOR LIGHT DUTY VEHICLES
Above 3500 feet in Elevation

Model Year	Passenger Cars				Light Duty Trucks			
	CO	NO_x	Exhaust HC	Evaporative HC	CO	NO_x	Exhaust HC	Evaporative HC
1960	130	1.9	10	7.1	130	1.9	10	7.1
1961	130	1.9	10	3.8	130	1.9	10	3.8
1962	130	1.9	10	3.8	130	1.9	10	3.8
1963	130	1.9	10	3.8	130	1.9	10	3.8
1964	130	1.9	10	3.0	130	1.9	10	3.0
1965	130	1.9	10	3.0	130	1.9	10	3.0
1966	76	1.8	6.8	3.0	76	1.8	6.8	3.0
1967	75	1.8	5.2	3.0	75	1.8	5.2	3.0
1968	74	2.2	6.0	3.0	74	2.2	6.0	3.0
1969	48	2.6	5.4	3.0	48	2.6	5.4	3.0
1970	72	2.8	6.1	0.5	72	2.8	6.1	0.5
1971	75	2.3	5.3	0.5	75	2.3	5.3	0.5
1972	42	2.3	4.9	0.2	42	2.3	4.9	0.2
1973	42	1.4	4.9	0.2	42	1.4	4.9	0.2
1974	42	1.4	4.9	0.2	42	1.4	4.9	0.2
1975	11	0.9	0.9	0.2	23	0.9	2.0	0.2
1976	11	0.9	0.9	0.2	20	0.9	0.9	0.2
1977	1.8	0.9	0.23	0.2	20	0.9	0.9	0.2
1978	1.8	0.31	0.23	0.2	20	0.9	0.9	0.2

TABLE 3

EMISSION RATES FOR HEAVY DUTY VEHICLES
Below 3500 Feet in Elevation

	Gasoline Trucks				Diesel Trucks			
Model Year	CO	NO_x	Exhaust HC	Evaporative HC	CO	NO_x	Exhaust HC	Evaporative HC
1960	140	9.4	17	8.2	20.4	34	3.4	0
1961	140	9.4	17	8.2	20.4	34	3.4	0
1962	140	9.4	17	8.2	20.4	34	3.4	0
1963	140	9.4	17	8.2	20.4	34	3.4	0
1964	140	9.4	17	8.2	20.4	34	3.4	0
1965	140	9.4	17	8.2	20.4	34	3.4	0
1966	140	9.4	17	8.2	20.4	34	3.4	0
1967	140	9.4	17	8.2	20.4	34	3.4	0
1968	140	9.4	17	3.0	20.4	34	3.4	0
1969	140	9.4	17	3.0	20.4	34	3.4	0
1970	130	9.2	16	3.0	20.4	34	3.4	0
1971	130	9.2	16	3.0	20.4	34	3.4	0
1972	130	9.2	13	3.0	20.4	34	3.4	0
1973	130	9.2	13	0.2	19	26	2.6	0
1974	130	9.2	13	0.2	19	26	2.6	0
1975	97	5.7	8.1	0.2	14	16	1.6	0
1976	97	5.7	8.1	0.2	14	16	1.6	0
1977	81	2.8	4.1	0.2	12	8	0.8	0
1978	81	2.8	4.1	0.2	12	8	0.8	0

TABLE 4

EMISSION RATES FOR HEAVY DUTY VEHICLES
Above 3500 Feet in Elevation

Model Year	Gasoline Trucks CO	Gasoline Trucks NO_x	Gasoline Trucks Exhaust HC	Gasoline Trucks Evaporative HC	Diesel Trucks CO	Diesel Trucks NO_x	Diesel Trucks Exhaust HC	Diesel Trucks Evaporative HC
1960	210	5	19	8.2	31	18	3.8	0
1961	210	5	19	8.2	31	18	3.8	0
1962	210	5	19	8.2	31	18	3.8	0
1963	210	5	19	8.2	31	18	3.8	0
1964	210	5	19	8.2	31	18	3.8	0
1965	210	5	19	8.2	31	18	3.8	0
1966	210	5	19	8.2	31	18	3.8	0
1967	210	5	19	8.2	31	18	3.8	0
1968	210	5	19	3.0	31	18	3.8	0
1969	210	5	19	3.6	31	18	3.8	0
1970	190	4.9	18	3.0	31	18	3.8	0
1971	190	4.9	18	3.0	31	18	3.8	0
1972	190	4.9	15	3.0	31	18	3.8	0
1973	190	4.9	15	0.2	29	14	2.9	0
1974	190	4.9	15	0.2	29	14	2.9	0
1975	142	3.0	9	0.2	21	8	1.8	0
1976	142	3.0	9	0.2	21	8	1.8	0
1977	118	1.5	5	0.2	18	4	0.9	0
1978	118	1.5	5	0.2	18	4	0.9	0

TABLE 5

CO Deterioration Factors for Light Duty Vehicles

Age of Vehicle (years)

odel Year	1	2	3	4	5	6	7	8	≥ 9
965 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
966	1.13	1.21	1.24	1.25	1.28	1.29	1.31	1.32	1.34
967	1.11	1.18	1.23	1.29	1.35	1.40	1.46	1.50	1.56
968	1.24	1.35	1.41	1.47	1.53	1.58	1.63	1.67	1.72
969	1.42	1.53	1.59	1.63	1.68	1.71	1.75	1.79	1.82
970	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1971	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1972	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1973	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1974	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51.	1.56
1975	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77
1976 & later	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77

TABLE 6

NO_x Deterioration Factors for Light Duty Vehicles

Age of Vehicles (years)

Model Year	1	2	3	4	5	6	7	8
1965 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1967	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1969	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1970	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1971	1.11	1.18	1.20	1.21	1.22	1.00	1.00	1.00
1972	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25
1973	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25
1974	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25
1975	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25
1976 & later	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48

TABLE 7

Exhaust HC Deterioration Factors for Light Duty Vehicles

Model Year	Age of Vehicle (years) 1	2	3	4	5	6	7	8	$\geq$ 9
1965 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.[illegible]
1966	1.14	1.22	1.25	1.27	1.29	1.30	1.32	1.33	1.[illegible]
1967	1.07	1.10	1.12	1.14	1.15	1.17	1.18	1.20	1.2[illegible]
1968	1.12	1.18	1.21	1.23	1.26	1.28	1.30	1.32	1.3[illegible]
1969	1.10	1.16	1.18	1.21	1.23	1.25	1.28	1.29	1.3[illegible]
1970	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.2[illegible]
1971	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.2[illegible]
1972	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.2[illegible]
1973	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.2[illegible]
1974	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.2[illegible]
1975	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.4[illegible]
1976 & later	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.4[illegible]

TABLE 8

Deterioration Factors for Heavy Duty Vehicles
Both Gasoline and Diesel Powered

Model Year	Vehicle Age, Years 0	1	2	3	4	5	6	7	8	≥9
					CO Deterioration Factor					
1974 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 & later	1.00	1.24	1.35	1.43	1.50	1.57	1.63	1.69	1.73	1.77
					NO_x Deterioration Factor					
1974 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 & later	1.00	1.11	1.18	1.20	1.22	1.23	1.24	1.25	1.27	1.28
					Exhaust HC Deterioration Factor					
1974 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 & later	1.00	1.12	1.18	1.22	1.25	1.28	1.30	1.33	1.36	1.38

TABLE 9

Light Duty Passenger Vehicle Travel vs. Age

Vehicle Age (years)	% of Vehicles	Annual Mileage	% Distribution of Miles travel[illegible]
1	10.1	17,500	22.0
2	9.8	13,000	15.9
3	8.5	11,500	12.2
4	8.4	10,000	10.5
5	9.2	8,500	9.8
6	8.1	7,000	7.1
7	7.0	6,000	5.2
8	7.3	5,000	4.6
9	7.4	4,000	3.7
10	6.0	3,000	2.2
≥ 11	18.2	3,000	6.8
	100.0%		

TABLE 10

Light Duty Truck Travel vs. Age

Vehicle Age (years)	% of Vehicles	Annual Mileage	% Distribution of Miles traveled
1	10.4	20,000	26.2
2	12.6	14,000	22.2
3	8.2	12,000	12.4
4	7.9	10,000	10.0
5	7.6	7,000	6.7
6	5.6	6,000	4.2
7	4.8	5,000	3.0
8	5.2	4,500	3.0
9	5.5	3,000	2.1
10	4.9	2,500	1.5
≥ 11	27.3	2,500	8.6
	100.0		

TABLE 11

Heavy Duty Gasoline Truck Travel vs Age

Vehicle Age (years)	% of Vehicles	Annual Mileage	% Distribution of Miles Traveled
1	8.9	19,700	13.4
2	10.7	19,700	16.1
3	7.1	18,000	9.7
4	7.3	18,000	10.0
5	7.6	15,100	8.7
6	6.1	15,100	7.0
7	5.0	11,500	4.4
8	5.7	11,500	5.0
9	6.0	10,000	4.6
10	5.4	10,000	4.1
$\leq$ 11	30.2	7,370	17.0
	100.0%		

TABLE 12

Heavy Duty Diesel Truck Travel vs Age

Vehicle Age (years)	% of Vehicles	Annual Mileage	% Distribution Miles Traveled
1	11.4	78,600	15.9
2	9.1	78,600	12.7
3	9.5	72,000	12.2
4	10.6	72,000	13.6
5	8.5	60,200	9.1
6	6.4	60,200	6.8
7	8.4	45,700	6.8
8	6.9	45,700	5.6
9	6.0	39,900	4.3
10	4.6	39,900	3.3
≤ 11	18.6	29,400	9.7

TABLE 13

NEW LIGHT DUTY VEHICLE EMISSION STANDARDS

YEAR	STANDARD	COLD START TEST	HYDROCARBONS	CARBON MONOXIDE	OXIDES OF NITROGEN
Prior to controls		7-mode	850 ppm	3.4%	1000 ppm
		7-mode	(11 gm/mi)	(80 gm/mi)	(4 gm/mi)
		CVS-75	11	96	2.9
1966-1967	Calif.	7-mode	275 ppm	1.5%	no std.
1968-1969	Calif. & Federal	7-mode			
		50-100 CID	410 ppm	2.3%	no std.
		101-140 CID	350 ppm	2.0%	no std.
		over-140 CID	275 ppm	1.5%	no std.
1970	Calif. & Federal	7-mode	2.2 gm/mi	23 gm/mi	no std.
1971	Calif.	7-mode	2.2 gm/mi	23 gm/mi	4 gm/mi
	Federal	7-mode	2.2 gm/mi	23 gm/mi	-
1972	Calif.	7-mode or	1.5 gm/mi	23 gm/mi	3 gm/mi
		CVS-72	3.2 gm/mi	39 gm/mi	*3.2 gm/mi
	Federal	CVS-72	3.4 gm/mi	39 gm/mi	-
1973	Calif.	CVS-72	3.2 gm/mi	39 gm/mi	3 gm/mi
	Federal	CVS-72	3.4 gm/mi	39 gm/mi	3 gm/mi
1974	Calif.	CVS-72	3.2 gm/mi	39 gm/mi	2 gm/mi
	Federal	CVS-72	3.4 gm/mi	39 gm/mi	3 gm/mi

The values in parentheses are approximately equivalent values by 7-mode test.
ppm - parts per million concentration
gm/mi - grams per mile
7-mode - is a 137 second driving cycle test.
CVS-72 - is a Constant Volume Sample cold start test.

TABLE 13 (continued)

NEW LIGHT DUTY VEHICLE EMISSION STANDARDS

YEAR		STANDARD	COLD START TEST	HYDROCARBONS	CARBON MONOXIDE	OXIDES OF NITROGEN
1975	**PC	Calif.	CVS-75	0.9 gm/mi	9.0 gm/mi	2.0 gm/mi
	**PC	Federal	CVS-75	1.5 gm/mi	15 gm/mi	3.1 gm/mi
	**LDT	Calif.	CVS-75	2.0 gm/mi	20 gm/mi	2.0 gm/mi
	**LDT	Federal	CVS-75	2.0 gm/mi	20 gm/mi	3.1 gm/mi
1976	**PC	Calif.	CVS-75	0.9 gm/mi	9.0 gm/mi	2.0 gm/mi
	**PC	Federal	CVS-75	1.5 gm/mi	15 gm/mi	3.1 gm/mi
	**LDT	Calif.	CVS-75	0.9 gm/mi	17 gm/mi	2.0 gm/mi
	**LDT	Federal	CVS-75	2.0 gm/mi	20 gm/mi	3.1 gm/mi
1977	**PC	Calif.	CVS-75	0.9 gm/mi	9.0 gm/mi	2.0 gm/mi
	**PC	Federal	CVS-75	***0.41 gm/mi	***3.4 gm/mi	2.0 gm/mi
	**LDT	Calif.	CVS-75	0.9 gm/mi	17 gm/mi	2.0 gm/mi
	**LDT	Federal	CVS-75	NOT	ESTABLISHED	
1978	**PC	Calif.	CVS-75	NOT	ESTABLISHED	
	**PC	Federal	CVS-75	0.41 gm/mi	3.4 gm/mi	0.40 gm/mi
	**LDT	Calif	CVS-75	****-0.9gm/mi	****17 gm/mi	**** 2.0 gm/mi
	**LDT	Federal	CVS-75	NOT	ESTABLISHED	

CVS-75 - is a Constant Volume Sample test which includes cold and hot starts.
* - hot 7-mode
** - PC - Passenger Cars LDT-Light Duty Trucks
***-Subject to possible one-year delay
**** Assumed Value

Crankcase Emissions

On all new vehicles manufactured for sale in California after January 1, 1964, crankcase emissions are virtually zero. Comparable Federal standards became effective in 1968 for light-duty vehicles.

Evaporative Emissions

Evaporative emissions of hydrocarbons have been 6 gms/ test for light-duty vehicles since 1970, and 2 gms/test since 1972.

TABLE 14

NEW HEAVY DUTY VEHICLE EMISSION STANDARDS

YEAR	STANDARD	HYDRO-CARBONS	CARBON MONOXIDE	OXIDES OF NITROGEN
* 1969-1971	State-gasoline	275 ppm	1.5%	no std.
1972	State-gasoline	180 ppm	1.0%	no std.
1973-74	State-gasoline & diesel	HC + NO_x = 16 gm/BHP hr. CO = 40 gm/BHP hr.		
1975-76	State-gasoline & diesel	HC + NO_x = 10 gm/BHP hr. CO = 30 gm/BHP hr.		
1977	State-gasoline & diesel	HC + NO_x = 5 gm/BHP hr. CO = 25 gm/BHP hr.		

gm/BHP hr. grams per brake horsepower-hour

* Federal standards remained at this level through 1973. The Federal Government adopted standards for heavy-duty gasoline and diesel vehicles for 1974 and subsequent model years which are identical to California's 1973-74 standards.

State Smoke Standards

1971 and later vehicles may discharge smoke no darker than Ringelmann 1 or 20 percent opacity for up to 10 seconds.

Vehicles sold before 1971 may discharge smoke no darker than Ringelmann 2 or 40 percent opacity for up to 10 seconds.

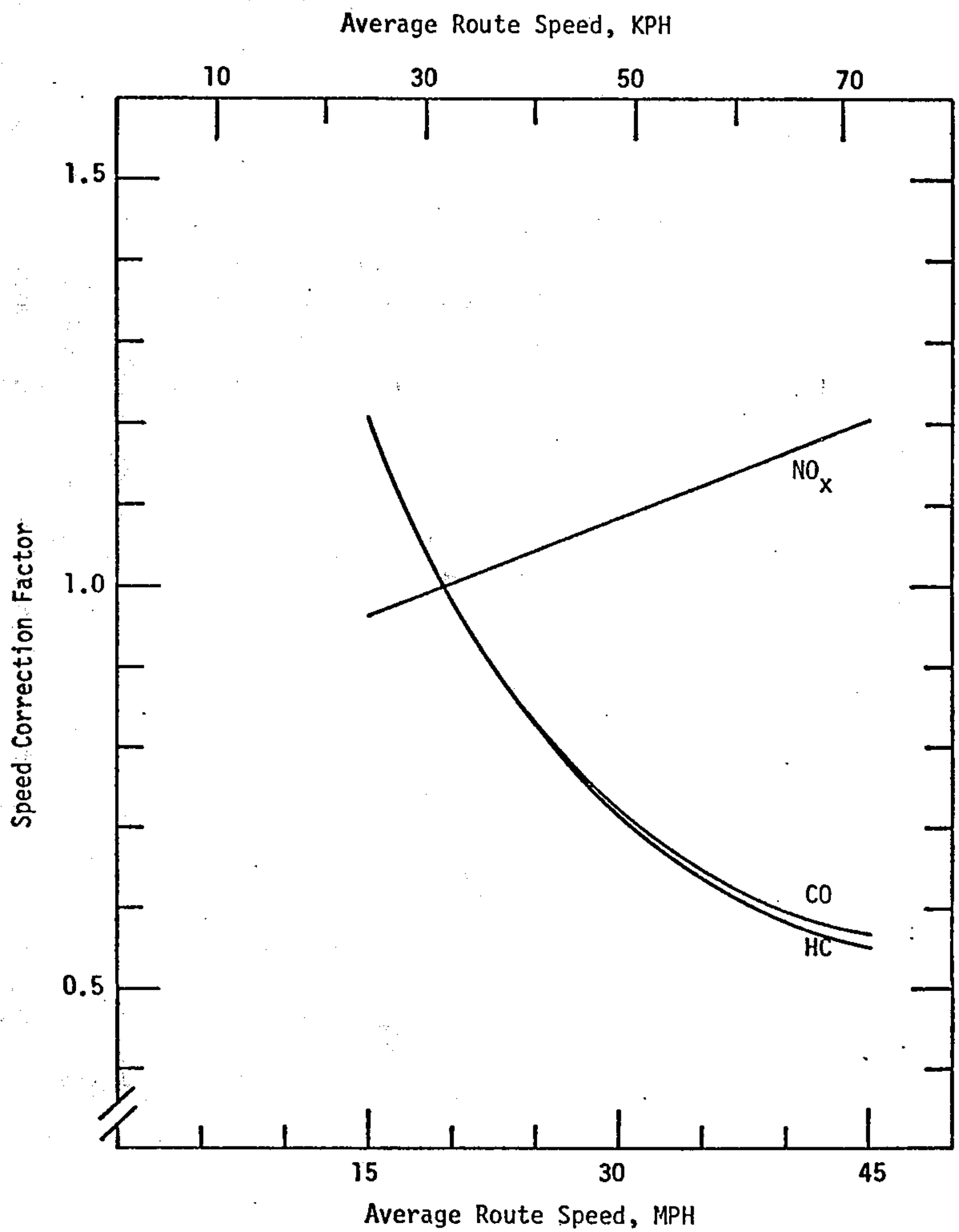
Crankcase Emissions

On all new vehicles manufactured for sale in California after January 1, 1964, crankcase emissions are virtually zero. Comparable Federal standards became effective in 1970 for heavy-duty vehicles.

Evaporative Emissions

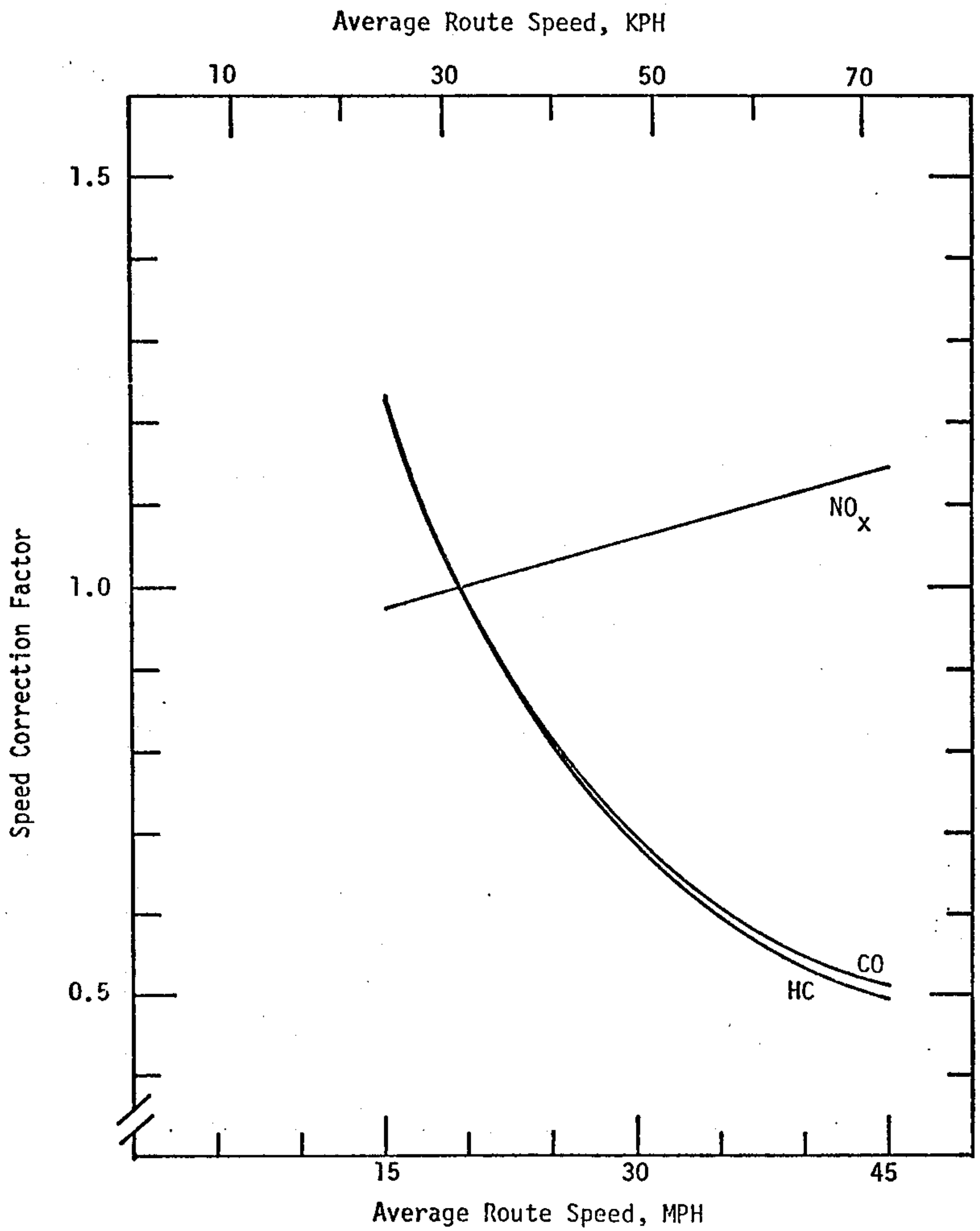
Evaporative emissions of hydrocarbons are 2 gms/test, effective 1973.

FIGURE 1



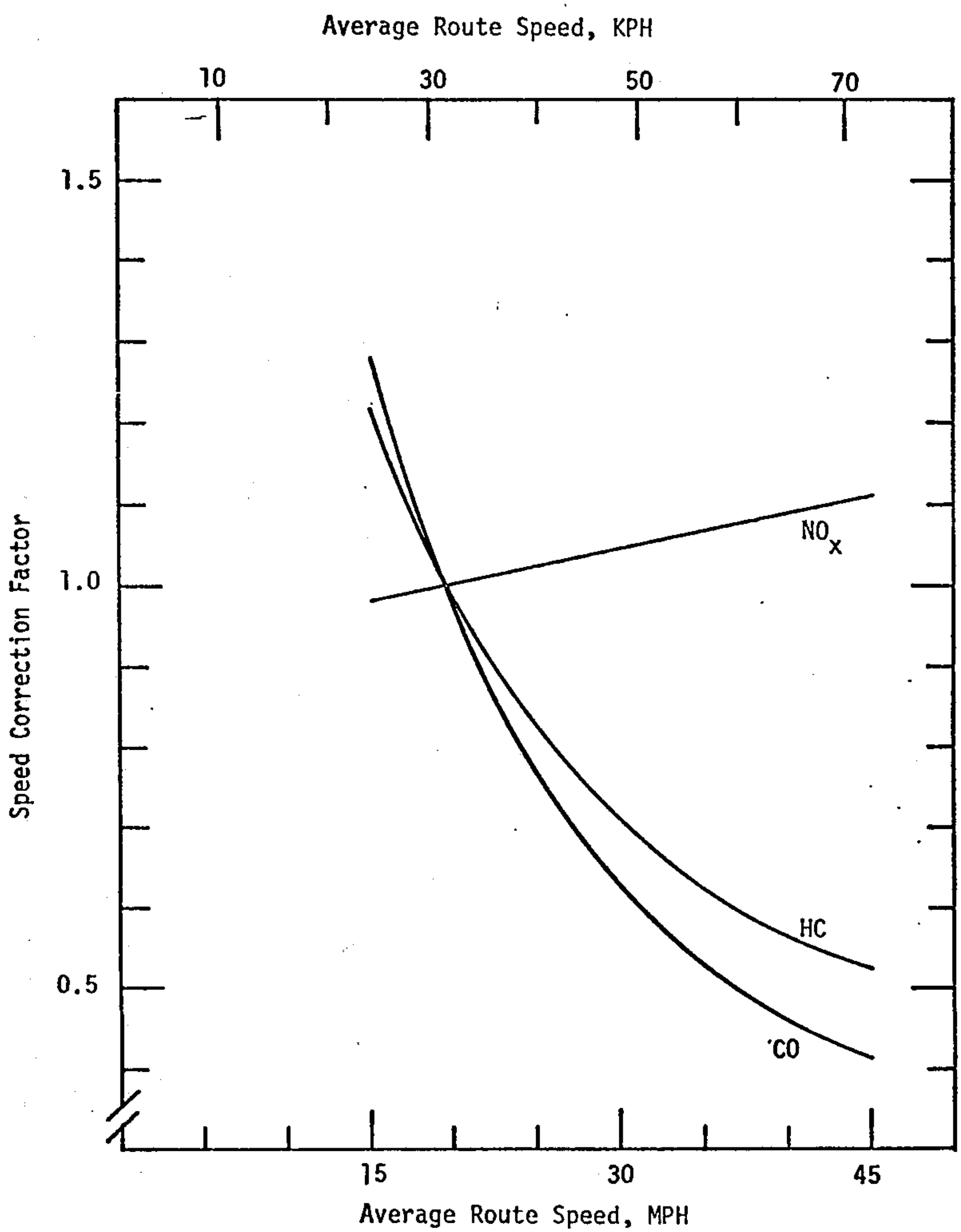
Speed Adjustment Factor for 1967 and Earlier Vehicles

FIGURE 2



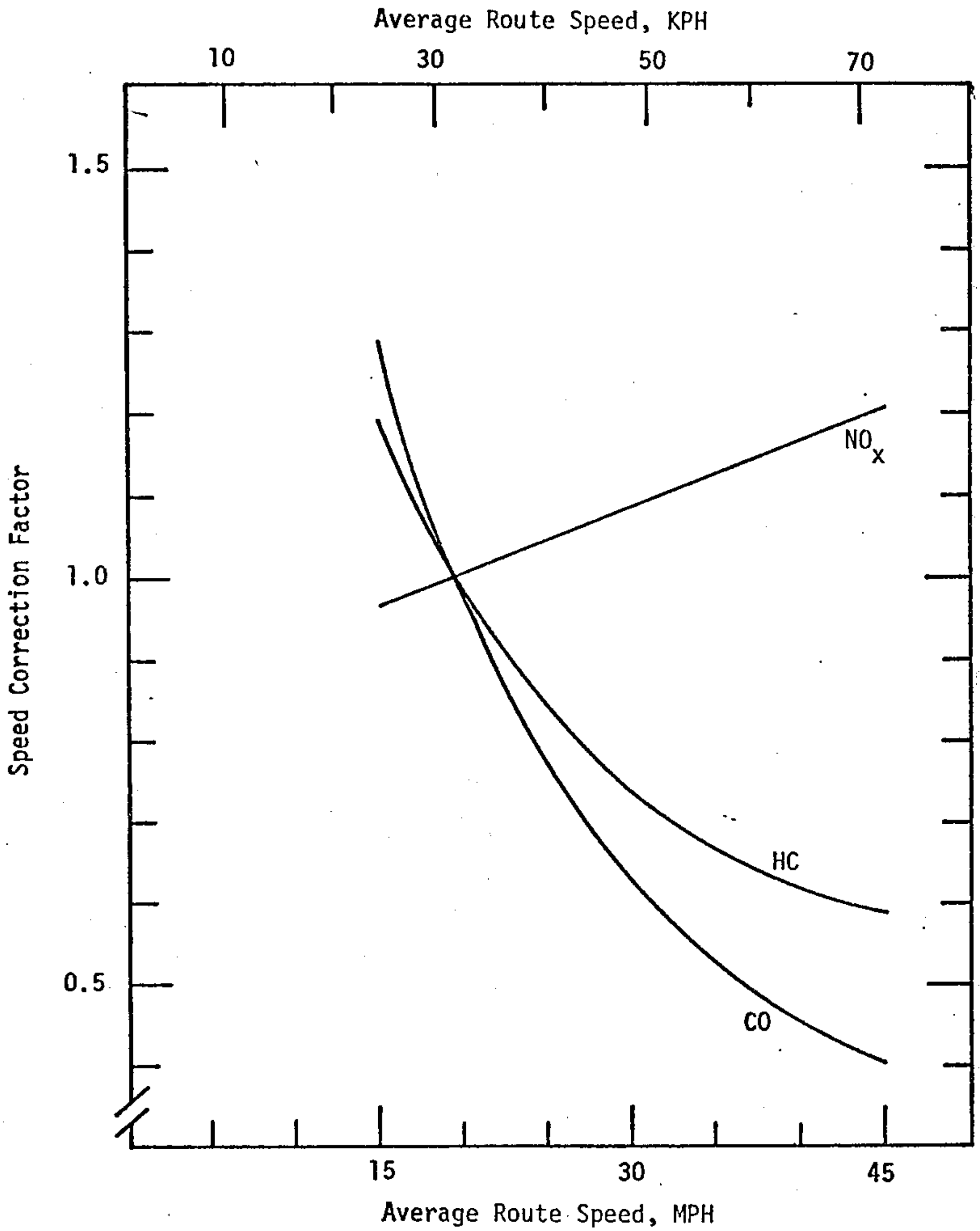
Speed Adjustment Factor for 1968 Vehicles

FIGURE 3



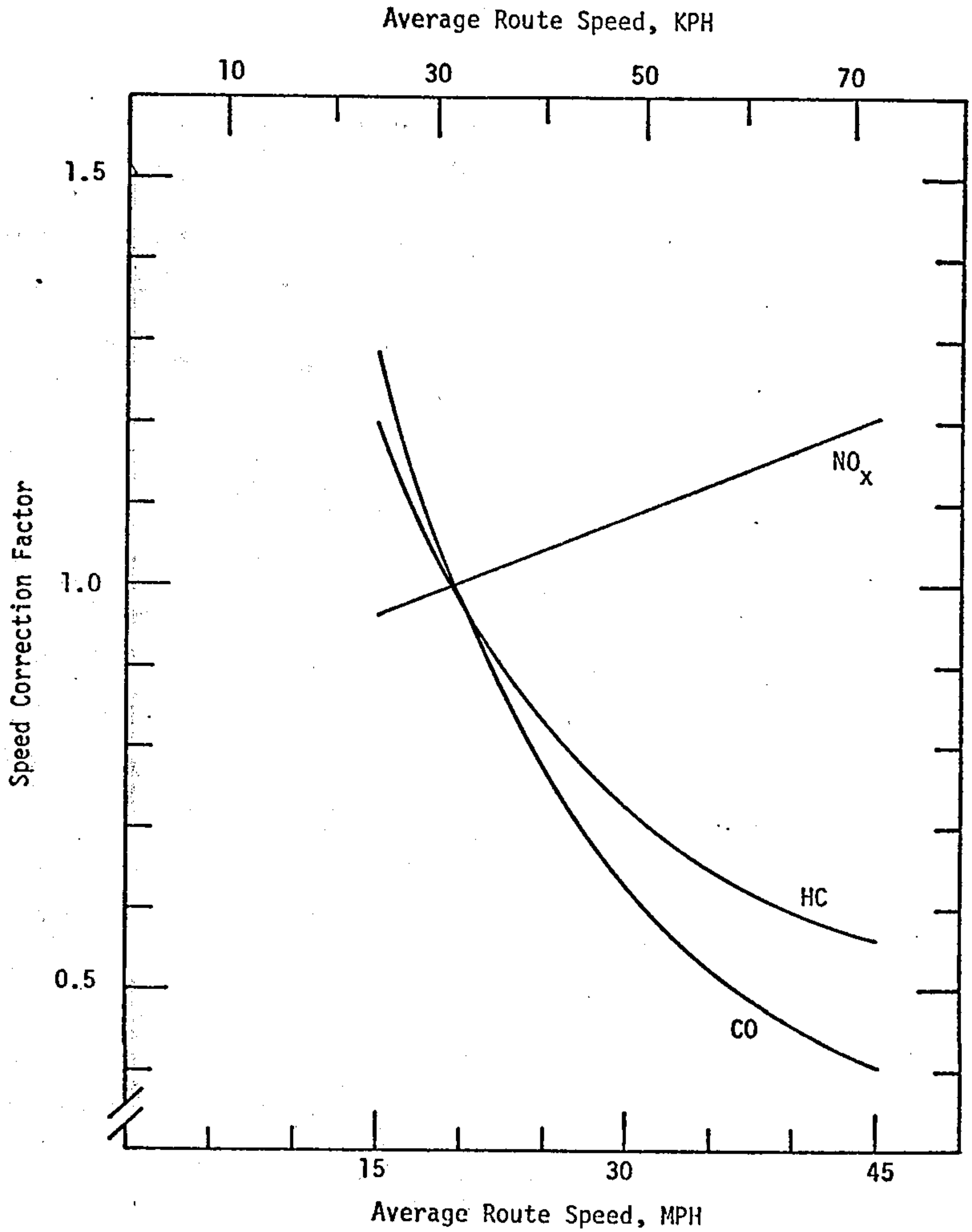
Speed Adjustment Factor for 1969 Vehicles

FIGURE 4



Speed Adjustment Factors for 1970 Vehicles

FIGURE 5



Speed Adjustment Factor for 1971 and later Vehicles

```
>QUIT
LOAD '%EMFAC' CLEAR

LAST LINE IS  2000
>LIST
1000 REM            ***** PROGRAM EMFAC *****

         CALCULATES EXPECTED POLLUTANTS FROM HIGHWAY
         TRAFFIC IN GRAMS/MILE FROM DATA INPUT FROM
                          TERMINAL

1005 REM  MODIFIED BY R. WEBER, SEPT. 1974
1010 REM  PROGRAMMED BY C. FRAZIER, JULY 1974 FOR

               ENVIRONMENTAL IMPROVEMENT SECTION
                  TRANSPORTATION LABORATORY
             CALIFORNIA DEPARTMENT OF TRANSPORTATION

1020 PRINT
1030 PRINT,'***** UPDATED SEPT. 13,1974 *****'
1040 PRINT'INCLUDES LATEST COMMENTS AND STANDARDS FROM ARB'
1050 PRINT
1060 REM
                  M = % VEHICLE DISTRIBUTION
                  L = DETERIORATION FACTORS - LDV
                  H = DETERIORATION FACTORS - HDV
1070 REM          S = SPEED CORRECTION FACTORS
                  F = VEHICLE EMISSION FACTORS

1080 LEMY=65      ! EARLIEST MODEL YEAR LIMIT - MAT L
1090 SEMY=65      ! EARLIEST MODEL YEAR LIMIT - MAT S
1100 FEMY=60      ! EARLIEST MODEL YEAR LIMIT - MAT F
1110 LLMY=76      ! LATEST   MODEL YEAR LIMIT - MAT L
1120 SLMY=71      ! LATEST   MODEL YEAR LIMIT - MAT S
1130 FLMY=78      ! LATEST   MODEL YEAR LIMIT - MAT F
1140 MAGE=11      ! AGE LIMIT FOR % DISTRIBUTION
1150 LAGE=9       ! AGE LIMIT FOR DETERIORIATION - LDV
1160 HAGE=9       ! AGE LIMIT FOR DETERIORIATION - HDV
1170 C,T=4,  T3=3 ! SEE BELOW

1180 REM          C(1) = AUTOMOBILES
                  C(2) = LT DUTY TRUCKS
                  C(3) = GAS POWERED HD TRUCKS
                  C(4) = DSL POWERED HD TRUCKS

1190 REM          T(1) = CARBON MONOXIDE
                  T(2) = NITROGEN OXIDES
                  T(3) = HYDORCARBONS - EXHAUST
                  T(4) = HYDROCARBONS - CRANKCASE & EVAP.

1200 DIM M(MAGE,C),L(T3,LEMY:LLMY,LAGE),H(T3,0:HAGE),
       S(SEMY:SLMY,3,4),F(FEMY:FLMY,C,T)

1210 OPEN '5:LAB:EMFILE',1,INPUT,OLD,BINARY,RANDOM
1220 MAT INPUT FROM 1 AT 1:M,L,H,S !

          ***** INPUT PROBLEM PARAMETERS *****

1230 PRINT'JOB TITLE':
1240 INPUT TIT$
```

```
1250 PRINT

1260 PRINT''PERCENT OF HDV THAT ARE DIESEL POWERED.'
1270 PRINT''IF NOT KNOWN, ENTER 10 FOR STATE AVERAGE':
1280 INPUT HDVD
1290 IF HDVD<=100 THEN 1310 ELSE PRINT'
      'PLEASE INPUT VALUE LESS THAN OR EQUAL TO 100':
1300 GOTO 1280
1310 HDVD=.01*HDVD
1320 PRINT

1330 PRINT''ELEVATION LESS THAN 3500 FEET (YES OR NO)':
1340 INPUT AN$
1350 IF AN$='YES' OR AN$='NO' THEN 1370 ELSE PRINT'
      'PLEASE ANSWER YES OR NO':
1360 GOTO 1340
1370 IF AN$='YES' THEN T$='LESS', K=2
              ELSE T$='GREATER', K=3
1380 MAT INPUT FROM 1 AT K:F
1390 CLOSE 1
1400 PRINT

1402 PRINT''IS STUDY WITHIN L.A.,VENTURA,ORANGE,SANTA BARBARA,'
1403 PRINT''SAN BERNADINO OR RIVERSIDE COUNTIES? (YES OR NO)':
1404 INPUT ANN$
1406 PRINT
1410 PRINT''REACTIVE HYDROCARBONS (YES OR NO)':
1420 INPUT AN$
1430 IF AN$='YES' OR AN$='NO' THEN 1450 ELSE PRINT'
      'PLEASE ANSWER YES OR NO':
1440 GOTO 1420
1450 IF AN$='YES' THEN HC$='REACTIVE HC', HC=1
                  ELSE HC$=' TOTAL  HC ', HC=0
1460 PRINT

1470 PRINT''ENTER NO. YEARS, PREDICTION YEARS':
1480 MAT INPUT NY(1),YR(NY(1))
1490 PRINT

1500 PRINT''NUMBER OF CALCULATIONS FOR EACH YEAR':
1510 INPUT NC
1520 PRINT

1530 DIM PCT(NC),SPD(NC)
1540 PRINT''ENTER %HDV, SPEED FOR:'
1550     FOR I=1 TO NC
1560     PRINT'''CALC. ':I:TAB(15):
1570     INPUT PCT(I),SPD(I)
1580     IF PCT(I)<=100 THEN 1600 ELSE PRINT'
          'INVALID INPUT - TRY AGAIN'
1590     GOTO 1560
1600     PCT(I)=.01*PCT(I)
1610     SPD(I)=MIN(SPD(I),65)
1620     NEXT I !

          ***** BEGIN OUTPUT *****
    PAGE FOR EACH PREDICTION YEAR YR(I)

1630     FOR I=1 TO NY(1)
1640     IF YR(I)>99 THEN YR(I)=YR(I)-1900
```

```
1650     PRINT CHAR(12)
1660     PRINT
1670     PRINT:TIT$
1680     PRINT
1690     PRINT:'ALTITUDE ':T$:' THAN 3500 FEET'
1691    PRINT
1695    IF ANN$='YES' THEN PRINT:
            'PROJECT IS WITHIN THE 1966-70 RETROFIT AREA'
1700     PRINT IN FORM"/3B'PREDICTED VEHICLE EMISSION FACTORS'
          ' FOR YEAR'5%///4B'VEHICLE DISTRIBUTION - %    AVG. SPEED'
          4B'POLLUTANT  GRAMS/MILE'/":1900+YR(1)
1710     PRINT IN FORM"3B'AUTO LD TRK  HD GAS HD DSL     M.P.H.'
          5B'CO'4B 11% 4B'NOX'//":HC$
1720 REM
          ***** START AN INDIVIDUAL CALCULATION *****
            CALCULATE % DISTRIBUTION BY VEHICLE TYPE

1730        FOR J=1 TO NC
1740        IF J=1 THEN 1760
1750        IF PCT(J)-PCT(J-1) THEN PRINT ELSE 1770
1760        P4=HDVD*PCT(J), P3=PCT(J)-P4,
            K=1-PCT(J), P1=.87*K, P2=.13*K

1770        CO,HC1,HC2,NOX=0 ! INITIALIZE POLLUTANTS

          DETERMINE POLLUTION CONCENTRATION BY MODEL YEAR -MY

1780           FOR K=1 TO MAGE
1790           MY=YR(1)-K+1,
               LMY=MAX(LEMY,MIN(MY,LLMY)),
               FMY=MAX(FEMY,MIN(MY,FLMY)),
               SMY=MAX(SEMY,MIN(MY,SLMY))
1800           C1=P1*M(K,1), C2=P2*M(K,2),
               C3=P3*M(K,3), C4=P4*M(K,4) !

               ***** LIGHT DUTY VEHICLES *****

1810           AGE=MIN(K,LAGE)
1820           TC=L(1,LMY,AGE)*(C1*F(FMY,1,1)+C2*F(FMY,2,1))
1830           TN=L(2,LMY,AGE)*(C1*F(FMY,1,2)+C2*F(FMY,2,2))
1840           TH=L(3,LMY,AGE)*(C1*F(FMY,1,3)+C2*F(FMY,2,3)) !

               AFTER 1974, CORRECT FOR RETROFIT KITS ON
                   1966 TO 1970 MODEL YEAR VEHICLES

1842          IF ANN$='NO' THEN 1870
1850           IF YR(1)<75 THEN 1870
1860           IF MY>65 AND MY<71 THEN
                  TC=.89*TC, TN=.63*TN, TH=.66*TH !

               ***** HEAVY DUTY VEHICLES *****

1870           IF MY>74 THEN AGE=MIN(K,HAGE) ELSE AGE=0
1880           TC=TC+H(1,AGE)*(C3*F(FMY,3,1)+C4*F(FMY,4,1))
1890           TN=TN+H(2,AGE)*(C3*F(FMY,3,2)+C4*F(FMY,4,2))
1900           TH=TH+H(3,AGE)*(C3*F(FMY,3,3)+C4*F(FMY,4,3)) !

               CORRECT CONCENTRATIONS FOR SPEED

1910           RC=MIN(SPD(J),S(SMY,1,2)/(2*S(SMY,1,3))),
```

```
                RH=MIN(SPD(J),S(SMY,3,2)/(2*S(SMY,3,3)))
1920            CO=EXP(S(SMY,1,1)-S(SMY,1,2)*RC+S(SMY,1,3)*RC*RC)*
                   TC/S(SMY,1,4)+CO
1930            NOX=(S(SMY,2,1)+S(SMY,2,2)*SPD(J))*TN/S(SMY,2,4)+NOX
1940            HC1=EXP(S(SMY,3,1)-S(SMY,3,2)*RH+S(SMY,3,3)*RH*RH)*
                    TH/S(SMY,3,4)+HC1 !

                ADD CRANKCASE & EVAPORATIVE HYDROCARBONS

1950            HC2=HC2+C1*F(FMY,1,4)+C2*F(FMY,2,4)
                     +C3*F(FMY,3,4)+C4*F(FMY,4,4)
1960            NEXT K !

                PRINT POLLUTANT CONCENTRATION

1970          IF HC THEN THC=.75*HC1+.67*HC2
                   ELSE THC=HC1+HC2
1980      .   PRINT IN FORM'5%.% 4%.% 6%.% 5%.% 9% 7%.%% 2(8%.%%)/':
               100*P1,100*P2,100*P3,100*P4,SPD(J),CO,THC,NOX
1990        NEXT J,1

2000 PRINT CHAR(12)
>

      TENET 210 TIME-SHARING SYSTEM  1643  09/13/74 32

-LOGIN
#
ACCOUNT?  452___5ILAB
PASSWORD?

-
```

COPY 5;LAB;%EMFILE TO TEL

```
001 .220 .262 .134 .159
002 .159 .222 .161 .127
003 .122 .124 .097 .122
004 .105 .100 .100 .136
005 .098 .067 .087 .091
006 .071 .042 .070 .068
007 .052 .030 .044 .068
008 .046 .030 .050 .056
009 .037 .021 .046 .043
010 .022 .015 .041 .033
011 .068 .086 .170 .097
165 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
166 1.13 1.21 1.24 1.25 1.28 1.29 1.31 1.32 1.34
167 1.11 1.18 1.23 1.29 1.35 1.40 1.46 1.50 1.56
168 1.24 1.35 1.41 1.47 1.53 1.58 1.63 1.67 1.72
169 1.42 1.53 1.59 1.63 1.68 1.71 1.75 1.79 1.82
170 1.18 1.32 1.38 1.40 1.44 1.47 1.50 1.51 1.56
171 1.18 1.32 1.38 1.40 1.44 1.47 1.50 1.51 1.56
172 1.18 1.32 1.38 1.40 1.44 1.47 1.50 1.51 1.56
173 1.18 1.32 1.38 1.40 1.44 1.47 1.50 1.51 1.56
174 1.18 1.32 1.38 1.40 1.44 1.47 1.50 1.51 1.56
175 1.34 1.77 2.14 2.42 2.73 2.99 3.26 3.48 3.77
176 1.34 1.77 2.14 2.42 2.73 2.99 3.26 3.48 3.77
265 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
266 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
267 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
268 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
269 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
270 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
271 1.11 1.18 1.20 1.21 1.22 1.23 1.24 1.25 1.26
272 1.11 1.18 1.20 1.21 1.22 1.23 1.24 1.25 1.26
273 1.11 1.18 1.20 1.21 1.22 1.23 1.24 1.25 1.26
274 1.11 1.18 1.20 1.21 1.22 1.23 1.24 1.25 1.26
275 1.11 1.18 1.20 1.21 1.22 1.23 1.24 1.25 1.26
276 1.34 1.77 2.14 2.42 2.73 2.99 3.26 3.48 3.77
365 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
366 1.14 1.22 1.25 1.27 1.29 1.30 1.32 1.33 1.35
367 1.07 1.10 1.12 1.14 1.15 1.17 1.18 1.20 1.21
368 1.12 1.18 1.21 1.23 1.26 1.28 1.30 1.32 1.35
369 1.10 1.16 1.18 1.21 1.23 1.25 1.28 1.29 1.31
370 1.05 1.10 1.13 1.15 1.17 1.20 1.22 1.24 1.26
371 1.05 1.10 1.13 1.15 1.17 1.20 1.22 1.24 1.26
372 1.05 1.10 1.13 1.15 1.17 1.20 1.22 1.24 1.26
373 1.05 1.10 1.13 1.15 1.17 1.20 1.22 1.24 1.26
374 1.05 1.10 1.13 1.15 1.17 1.20 1.22 1.24 1.26
375 1.45 1.95 2.40 2.76 3.14 3.46 3.79 4.07 4.42
376 1.45 1.95 2.40 2.76 3.14 3.46 3.79 4.07 4.42
401 1.00 1.24 1.35 1.43 1.50 1.57 1.63 1.69 1.73 1.77
402 1.00 1.11 1.18 1.20 1.22 1.23 1.24 1.25 1.27 1.28
403 1.00 1.12 1.18 1.22 1.25 1.28 1.30 1.33 1.36 1.38
465 5.33475 6.06584E-2 5.78421E-4 78.89
    3.17413 3.85334E-2     0       3.93
    2.98338 5.99767E-2 5.80943E-4  7.62
466 4.88181 6.21854E-2 6.18978E-4 49.44
    3.15629 2.98311E-2     0       3.74
    2.66145 5.98232E-2 5.63255E-4  5.50
467 4.88181 6.21854E-2 6.18978E-4 49.44
    3.15629 2.98311E-2     0       3.74
```

	2.66145	5.98232E-2	5.63255E-4	5.50
468	5.22263	6.51947E-2	6.00899E-4	65.08
	4.24644	2.71939E-2	0	4.78
	2.70316	6.63011E-2	5.98211E-4	5.12
469	5.20578	7.71552E-2	6.59770E-4	51.78
	5.83611	2.75849E-2	0	6.38
	2.54636	6.26878E-2	5.79923E-4	4.67
470	5.01179	7.71946E-2	6.40350E-4	42.30
	4.93157	4.66796E-2	0	5.85
	2.16247	5.69535E-2	5.58732E-4	3.53
471	5.01669	7.52438E-2	6.08591E-4	43.63
	4.49361	4.28722E-2	0	5.33
	2.04527	5.92347E-2	5.67343E-4	3.01

560	87	3.6	8.8	7.1	87	3.6	8.8	7.1	140	9.4	17	8.2	20.4	34	3.4	0
561	87	3.6	8.8	3.8	87	3.6	8.8	3.8	140	9.4	17	8.2	20.4	34	3.4	0
562	87	3.6	8.8	3.8	87	3.6	8.8	3.8	140	9.4	17	8.2	20.4	34	3.4	0
563	87	3.6	8.8	3.8	87	3.6	8.8	3.8	140	9.4	17	8.2	20.4	34	3.4	0
564	87	3.6	8.8	3.0	87	3.6	8.8	3.0	140	9.4	17	8.2	20.4	34	3.4	0
565	87	3.6	8.8	3.0	87	3.6	8.8	3.0	140	9.4	17	8.2	20.4	34	3.4	0
566	51	3.4	6.0	3.0	51	3.4	6.0	3.0	140	9.4	17	8.2	20.4	34	3.4	0
567	50	3.4	4.6	3.0	50	3.4	4.6	3.0	140	9.4	17	8.2	20.4	34	3.4	0
568	46	4.3	4.5	3.0	46	4.3	4.5	3.0	140	9.4	17	3.0	20.4	34	3.4	0
569	39	5.5	4.4	3.0	39	5.5	4.4	3.0	140	9.4	17	3.0	20.4	34	3.4	0
570	36	5.1	3.6	0.5	36	5.1	3.6	0.5	130	9.2	16	3.0	20.4	34	3.4	0
571	34	3.5	2.9	0.5	34	3.5	2.9	0.5	130	9.2	16	3.0	20.4	34	3.4	0
572	19	3.5	2.7	0.2	19	3.5	2.7	0.2	130	9.2	13	3.0	20.4	34	3.4	0
573	19	2.3	2.7	0.2	19	2.3	2.7	0.2	130	9.2	13	0.2	19.0	26	2.6	0
574	19	2.3	2.7	0.2	19	2.3	2.7	0.2	130	9.2	13	0.2	19.0	26	2.6	0
575	4.8	1.5	0.5	0.2	10.6	1.5	1.1	0.2	97	5.7	8.1	.2	14.0	16	1.6	0
576	4.8	1.5	0.5	0.2	9	1.5	0.5	0.2	97	5.7	8.1	.2	14.0	16	1.6	0
577	1.8	1.5	.23	0.2	9	1.5	0.5	0.2	81	2.8	4.1	.2	12.0	8	0.8	0
578	1.8	.31	.23	0.2	9	1.5	0.5	0.2	81	2.8	4.1	.2	12.0	8	0.8	0
660	130	1.9	10	7.1	130	1.9	10	7.1	210	5.0	19	8.2	31	18	3.8	0
661	130	1.9	10	3.8	130	1.9	10	3.8	210	5.0	19	8.2	31	18	3.8	0
662	130	1.9	10	3.8	130	1.9	10	3.8	210	5.0	19	8.2	31	18	3.8	0
663	130	1.9	10	3.8	130	1.9	10	3.8	210	5.0	19	8.2	31	18	3.8	0
664	130	1.9	10	3.0	130	1.9	10	3.0	210	5.0	19	8.2	31	18	3.8	0
665	130	1.9	10	3.0	130	1.9	10	3.0	210	5.0	19	8.2	31	18	3.8	0
666	76	1.8	6.8	3.0	76	1.8	6.8	3.0	210	5.0	19	8.2	31	18	3.8	0
667	75	1.8	5.2	3.0	75	1.8	5.2	3.0	210	5.0	19	8.2	31	18	3.8	0
668	74	2.2	6.0	3.0	74	2.2	6.0	3.0	210	5.0	19	3.0	31	18	3.8	0
669	48	2.6	5.4	3.0	48	2.6	5.4	3.0	210	5.0	19	3.0	31	18	3.8	0
670	72	2.8	6.1	0.5	72	2.8	6.1	0.5	190	4.9	18	3.0	31	18	3.8	0
671	75	2.3	5.3	0.5	75	2.3	5.3	0.5	190	4.9	18	3.0	31	18	3.8	0
672	42	2.3	4.9	0.2	42	2.3	4.9	0.2	190	4.9	15	3.0	31	18	3.8	0
673	42	1.4	4.9	0.2	42	1.4	4.9	0.2	190	4.9	15	0.2	29	14	2.9	0
674	42	1.4	4.9	0.2	42	1.4	4.9	0.2	190	4.9	15	0.2	29	14	2.9	0
675	11	0.9	0.9	0.2	23	0.9	2.0	0.2	142	3.0	9	0.2	21	8	1.8	0
676	11	0.9	0.9	0.2	20	0.9	0.9	0.2	142	3.0	9	0.2	21	8	1.8	0
677	1.8	0.9	.23	0.2	20	0.9	0.9	0.2	118	1.5	5	0.2	18	4	0.9	0
678	1.8	.31	.23	0.2	20	0.9	0.9	0.2	118	1.5	5	0.2	18	4	0.9	0

SECTION 5

AIR POLLUTION METEOROLOGY AND ATMOSPHERIC TURBULENCE

I. Importance of Meteorology

A. Determines how pollutants are transported and dispersed.

B. Indicates areas of high air pollution potential.

C. Indicates the best type of highway design which disperses pollutants most efficiently (e.g. elevated vs. cut sections).

D. Indicates the most favorable highway route in terms of dispersion of pollutants

E. Determines the most probable and worst meteorological conditions to disperse pollutants.

F. Meteorological parameters are inputs to all air quality models which predict air quality.

G. Most important meteorological parameters which effect air quality are wind speed and temperature stratification.

II. Scale of Motion

A. Microscale
B. Mesoscale
C. Synoptic
D. Macroscale
E. See Figure 5-1

SCALES OF MOTION

SCALE	VERTICAL	HORIZONTAL	PARAMETERS
Microscale	Surface to 100 m	EP→100–400 m	① Small turbulent eddies ② Surface lapse rates ③ Topographic effects ④ Boundry layer
Mesoscale	Surface to 2000 m	Towns, cities air pollution control district jurisdiction	① Large turbulent eddies ② Land & sea breezes ③ Urban heat island
Synoptic	Surface to 10,000-15,000 m	Size of states continents	① Storm systems ② Cloud formations ③ Weather forecast
Macroscale	Global	Global	① Rotation of planet ② Differential Solar heating ③ Atmospheric geometry

FIGURE 5-1

III. Specification of Winds and Stability in Air Pollution Meteorology

A. Wind

1. A vector quantity - speed and direction must be specified

2. Streamlines - set of lines indicating wind direction at a given time in a particular region. (See pages 43 through 45 in Meteorology Manual.)

3. Trajectory - the path in space which a parcel of air follows in response to the wind field.

4. Isotachs - set of lines giving the wind speed distribution over a particular region at a given time.

5. Wind Rose - a circular histogram of wind directions at a particular point, showing the climatology of the wind velocity vector.

•See Figure 5-2

6. Vertical variation of the wind - wind shear.

•Function of surface roughness

$$\text{wind shear} = \frac{\partial \bar{u}}{\partial z}$$

•See Figure 5-3

WIND ROSES

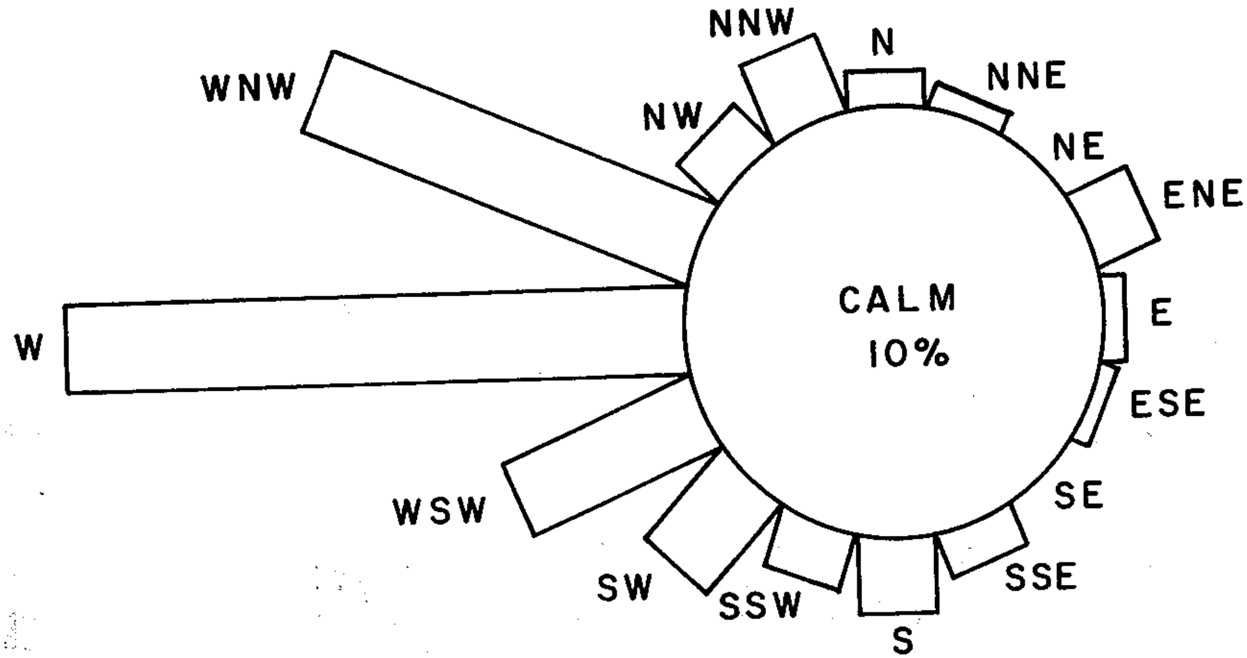
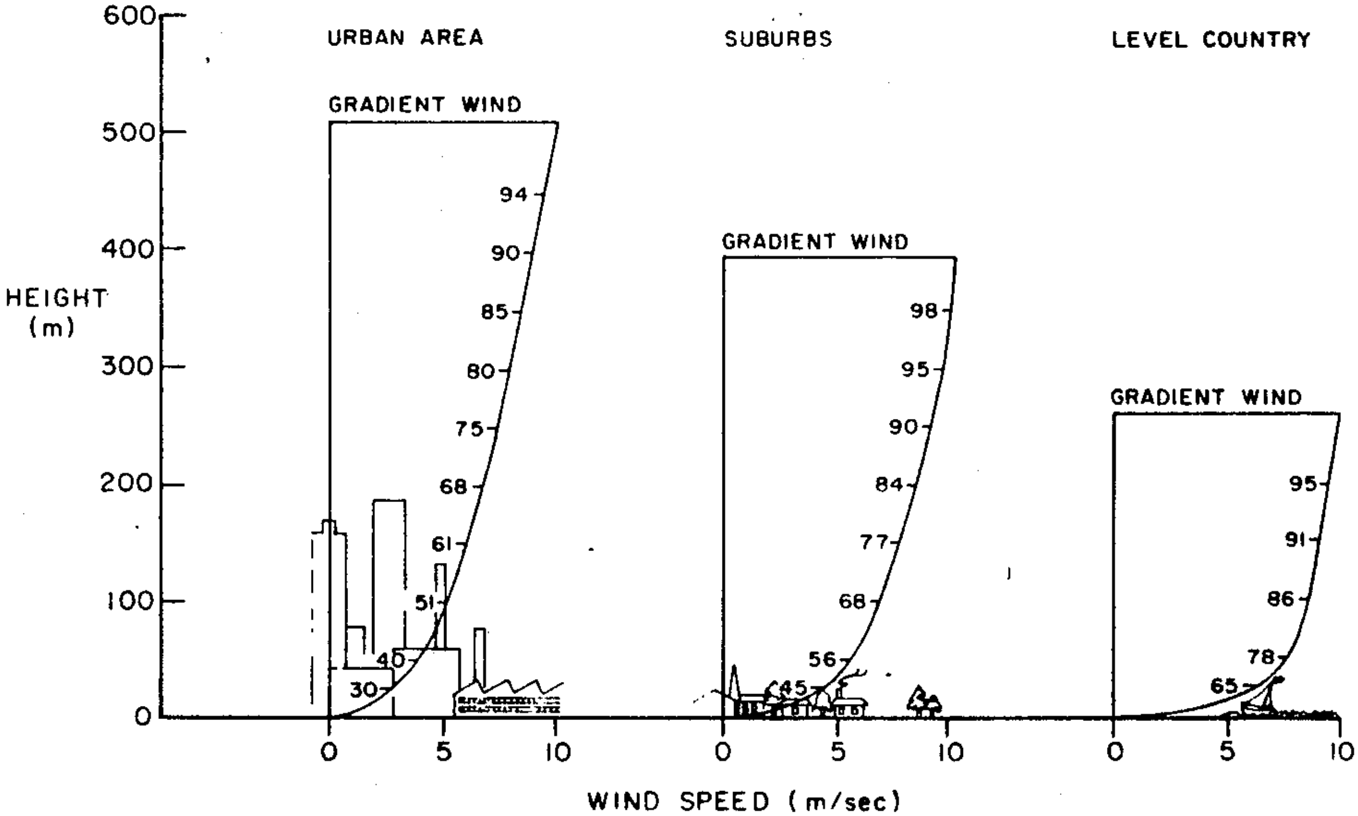


FIGURE 5-2



SOURCE: "Prediction of the Dispersion of Airborne Effluent" 1968 (ASME)

EFFECT OF TERRAIN ROUGHNESS ON THE WIND SPEED PROFILE

FIGURE 5-3

B. Temperature Stratification

1. Temperature and potential temperature.

2. Temperature soundings - See Figure 5-4.

3. Temperature Time Sections - time height representation of temperature stratification, useful technique for following and predicting day-to-day variations. See Figure 5-5.

4. Surface layer vertical temeprature gradients: effects of land use.

IV. Macroscale Considerations

A. Global regions of subsidence and formation of elevated inversion layers.

B. Global air stagnation regions.

1. Subtropical high pressure systems.

- Pacific high
- Bermuda high

V. Synoptic Scale Weather Systems and Air Quality.

A. Structure of westerly waves and fronts.

1. The jet stream
2. Location of cold and warm air, precipitation

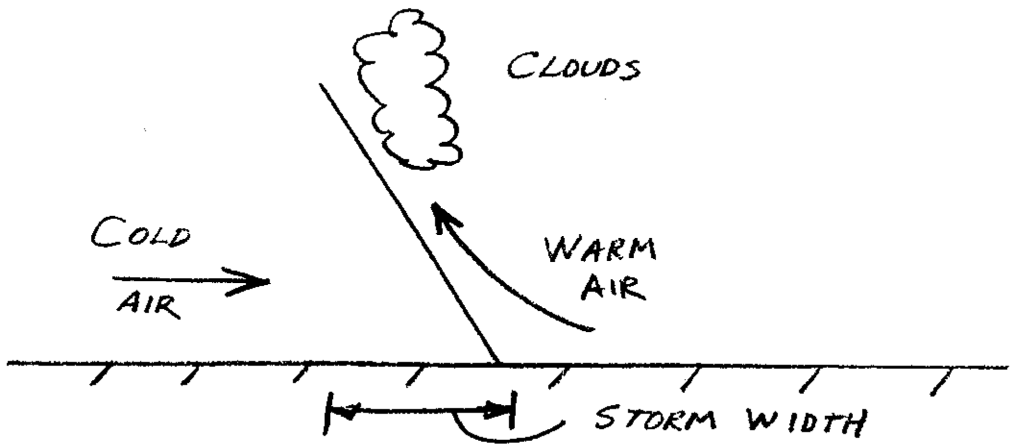
B. Preferred locations of enhanced convective mixing vs. air stagnation.

C. Cold Front Characteristics:

1. Have steep slopes due to friction of earth's surface.

2. Cause warm air to rise resulting in cloud formations.

3. Storms are violent with narrow widths.



D. Warm Front Characteristics:

1. Have shallow slopes.
2. Weather is less violent than cold fronts.
3. Has wider weather band.
4. Lower wind speeds.

E. General Characteristics of High and Low Pressure Areas:

1. Winds blow from <u>high</u> to <u>low</u> pressure areas.

2. In Northern Hemisphere winds blow clockwise around high pressure cells and counterclockwise around low pressure cells.

F. Air Quality Related to Pressure Systems.

1. High pressure areas tend to stagnate:

   a. Clear skies
   b. Strong surface inversions at night
   c. Light wind speed, bad ventilation
   d. Bad for air pollution
   e. Flat pressure gradient

2. Low pressure areas result in:

   a. High surface winds
   b. Good circulation and ventilation
   c. Best for air pollution
   d. Steep pressure gradient

G. Santa Ana and Northerly Winds.

TYPICAL DIURNAL VARIATION OF ATMOSPHERIC STABILITY

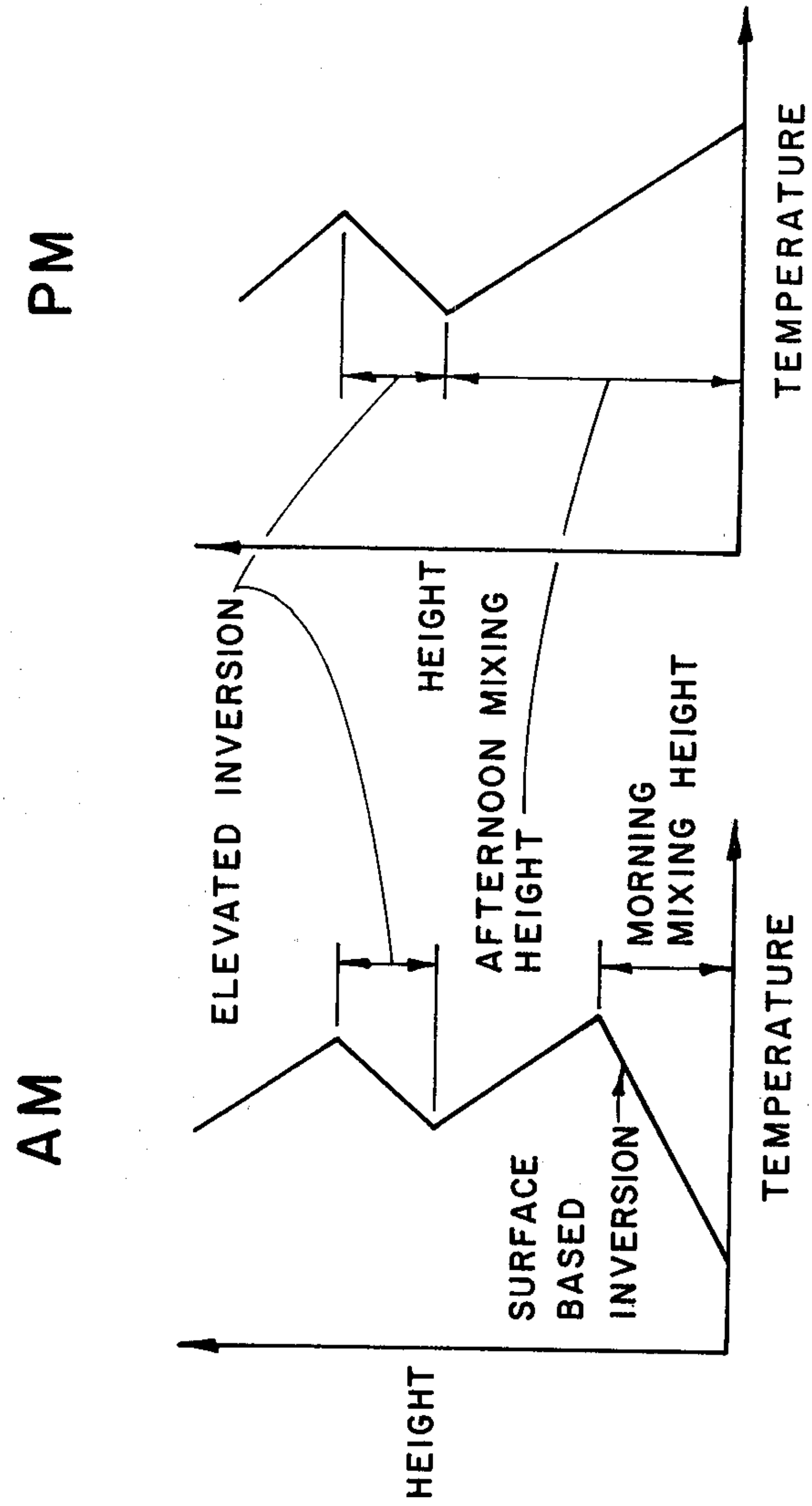


FIGURE 5-4

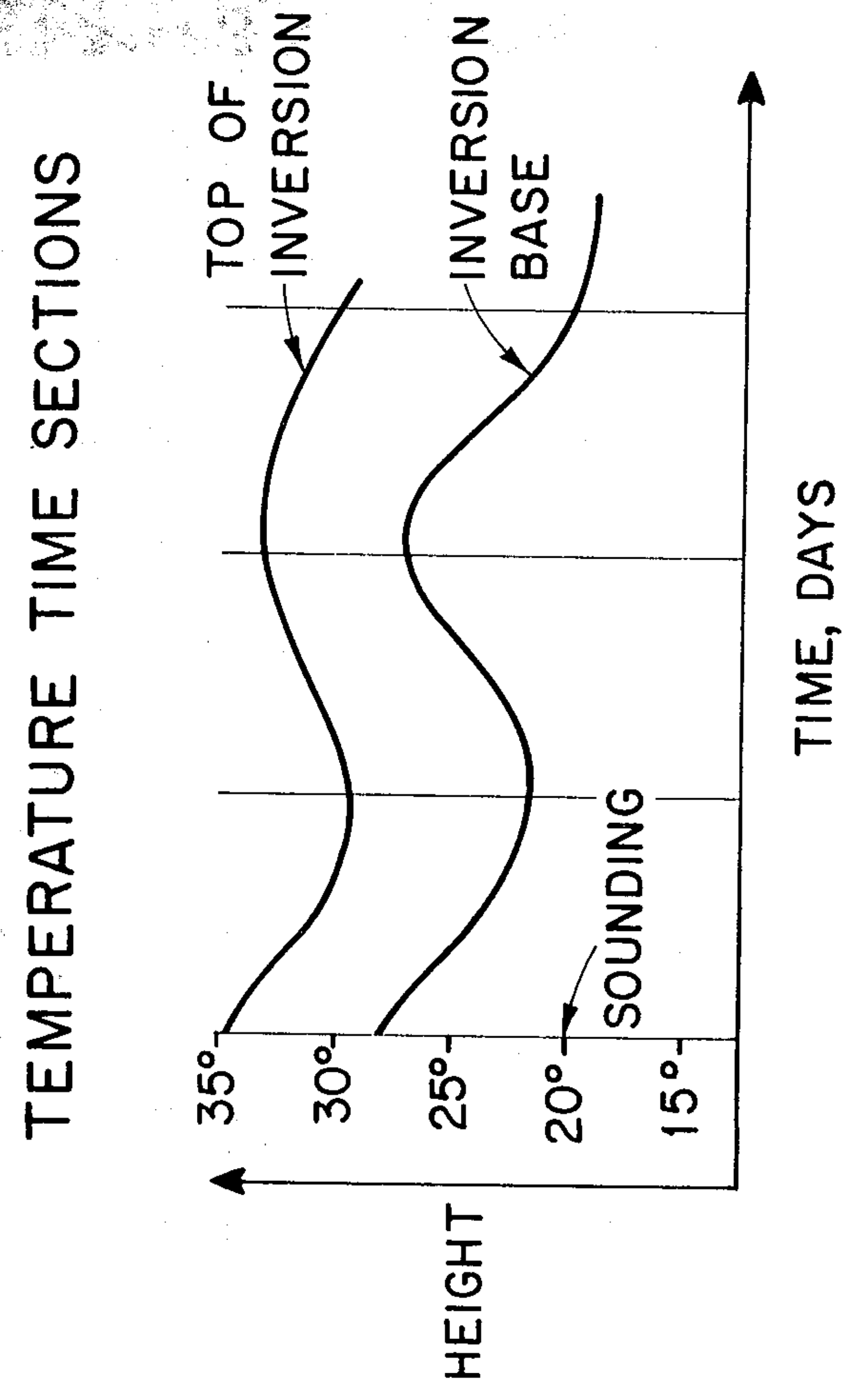
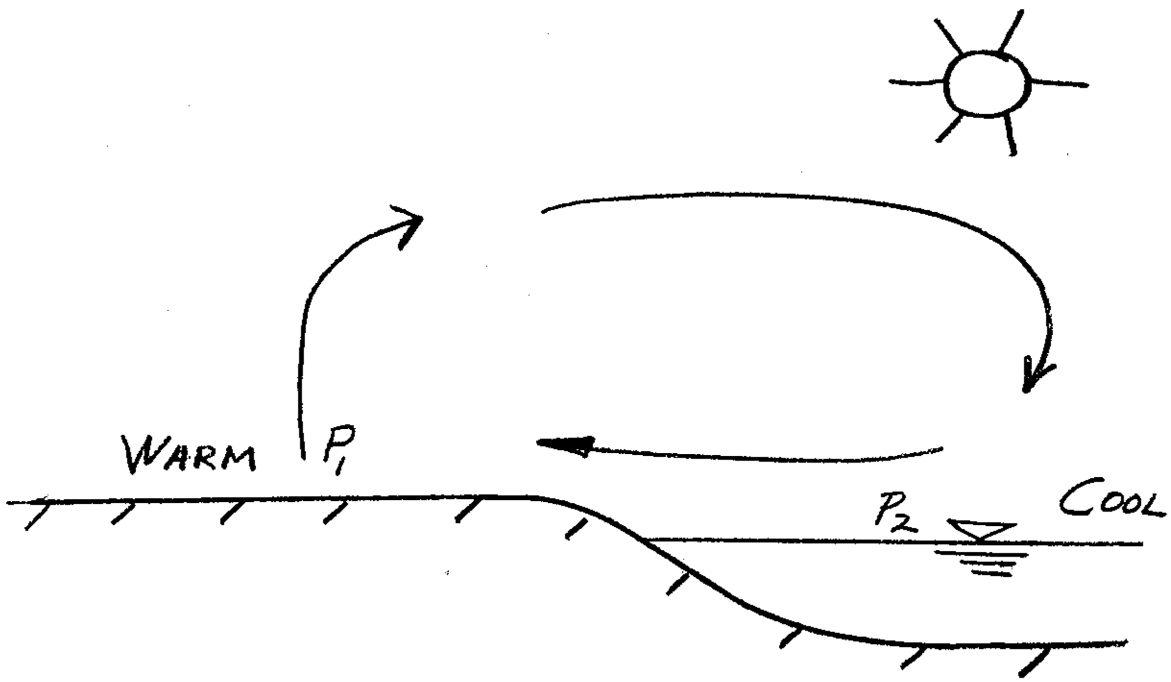

TEMPERATURE TIME SECTIONS
TOP OF INVERSION
INVERSION BASE
SOUNDING
35°
30°
25°
20°
15°
HEIGHT
TIME, DAYS

Figure 5-5

VI. Meso- and Micro- Scale Meteorology and Air Quality

A. Mesoscale Wind Systems

1. Sea or lake breeze - daytime conditions.

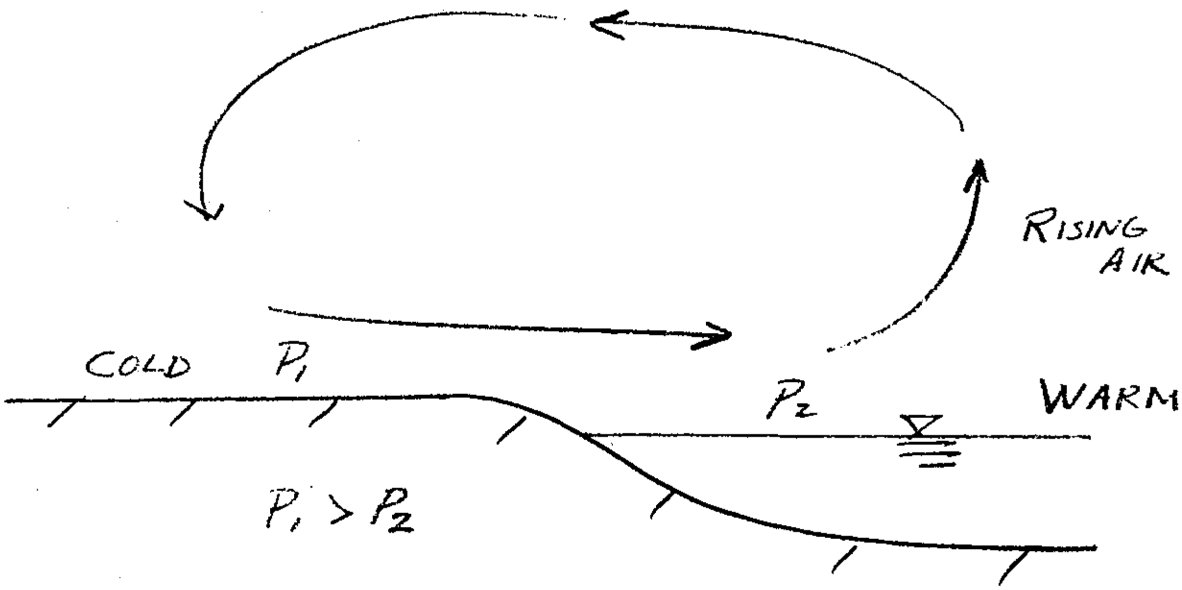


Temperature difference → changes in air densities → Pressure gradient force → Wind

$P_2 > P_1$ force

Sea breezes are generally strong near ocean. Most dominating when their exists a maximum temperature difference between land and water. Therefore summertime is generally the season of a dominating sea breeze.

2. Land Breeze - occur during night periods and early mornings (mesoscale)



3. Mountain breeze system

B. Nocturnal Drainage Winds - similar to land breeze. Strongly related to topographic effects (microscale)

1. Function of relative air densities between ground surface and air.

2. Function of terrain.
3. Function of slope of terrain.
4. Function of surface roughness.
5. Generally light winds $<$ 7 mph.

6. Most dominating during winter because maximum radiation cooling of land surface.

7. See Figure 5-6

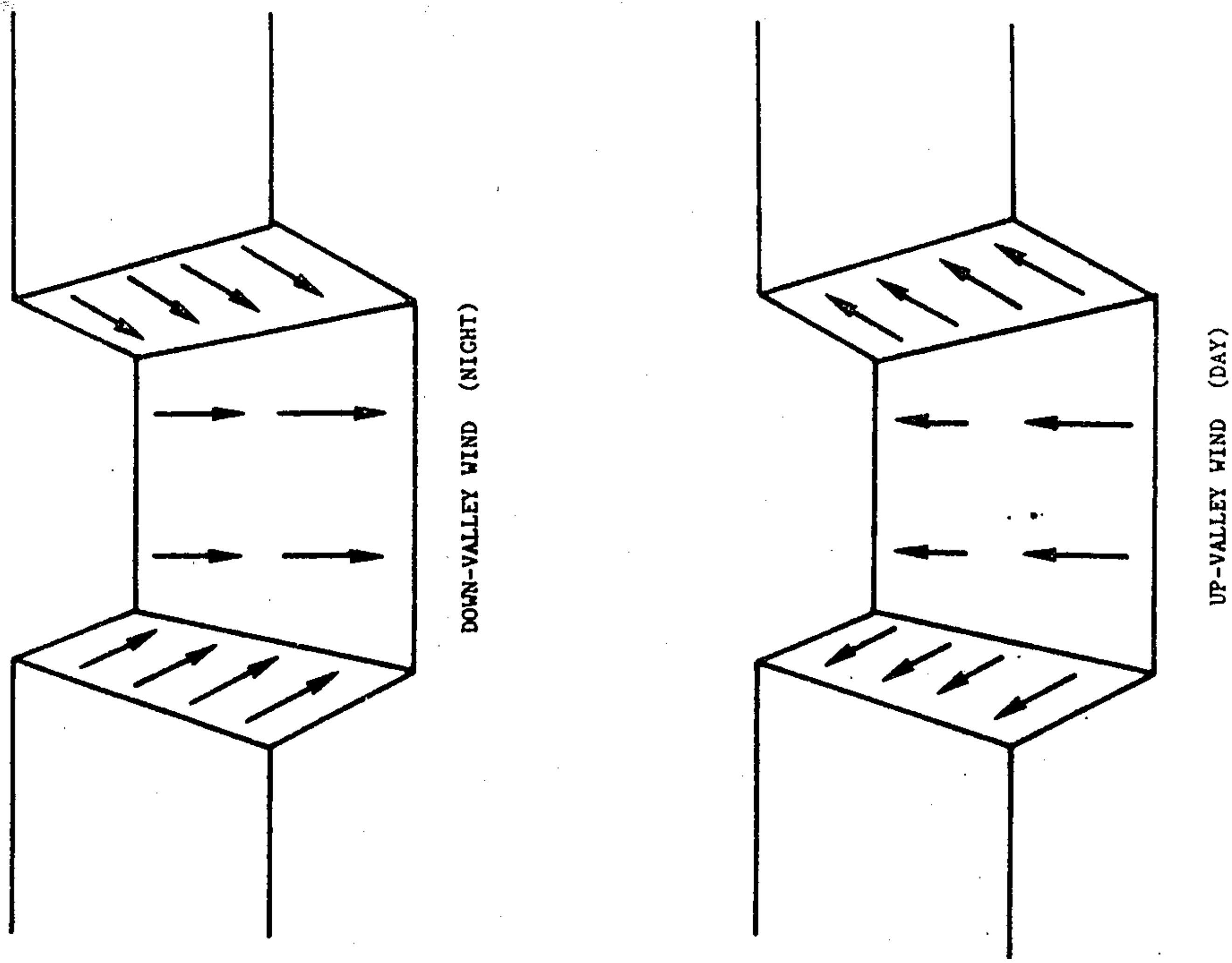


FIGURE 5-6

C. Mesoscale temperature stratification

1. Environmental Lapse Rate - Change of ambient temperature with height

2. Nocturnal or Surface Based Inversions

3. Elevated Inversions

4. Effects of inversions on mixing and air quality

    1. Subsidence - most dominating in summer in west.

    2. Sea breeze
    3. Frontal

        - High vs. low elevated inversions
        - Surface base inversion

D. Microscale Stability: Effect of land use and wind speed

E. Effects of Topography on Wind Flow and Pollution Dispersion

1. Effects of elevated inversion - See Figure 5-7, 8
2. Channeling winds - See Figure 5-9
3. Uneven heating of ground surface - See Figure 5-10
4. Drainage winds and up-valley winds - See Figure 5-6
5. Effects of valleys and passes - See Figure 5-11

F. Wind Direction Reversal with Height

1. Occurs for sea breezes and other mesoscale wind systems.
2. See Figure 5-12

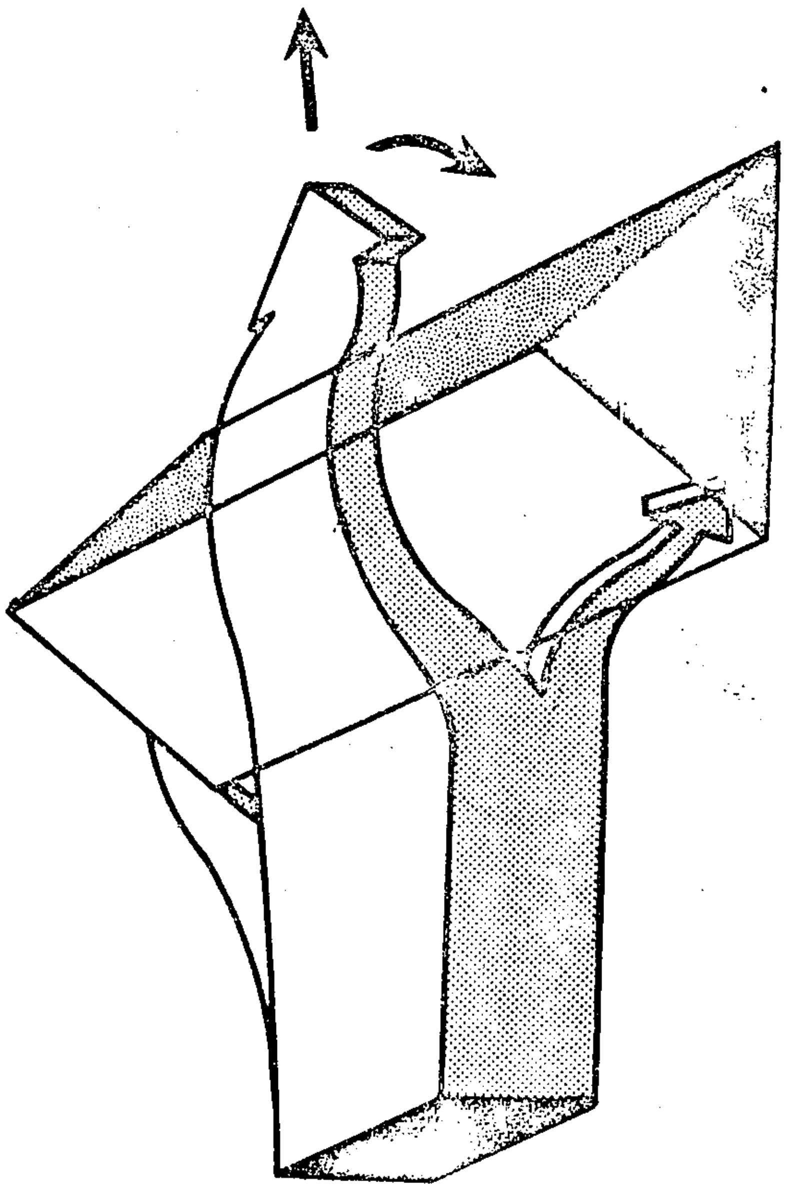


FIGURE 5-7

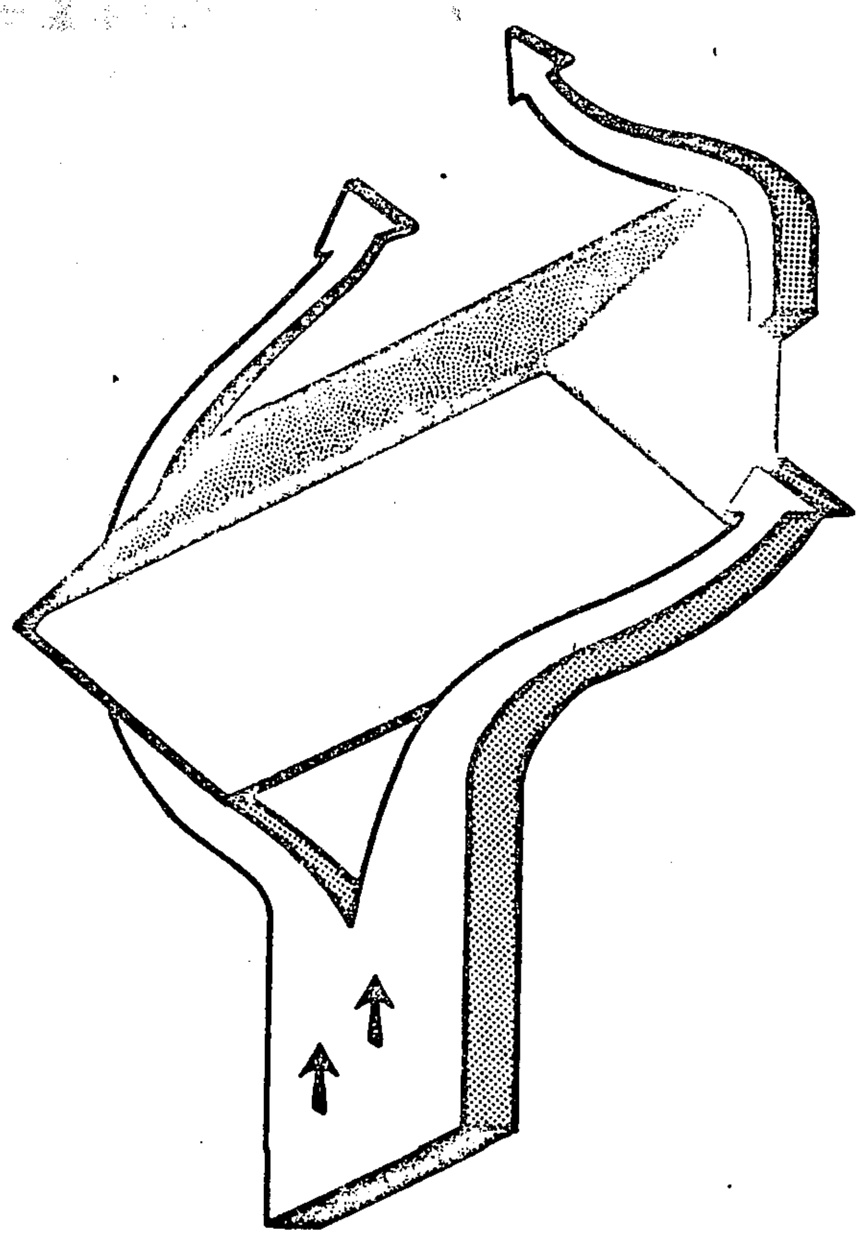
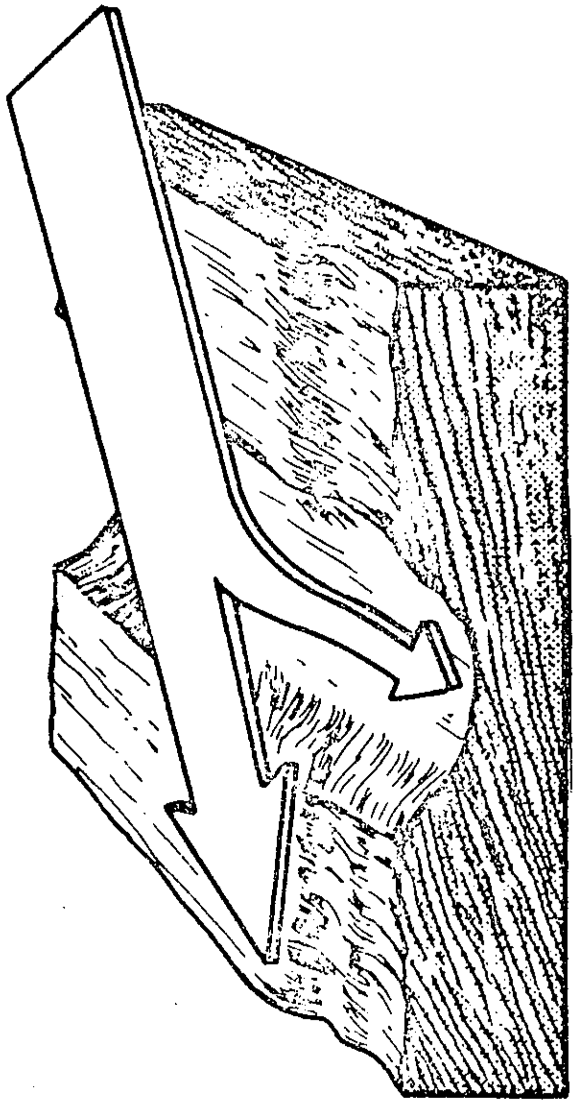


FIGURE 5-8



THE CHANNELING OF WIND BY A VALLEY

FIGURE 5-9

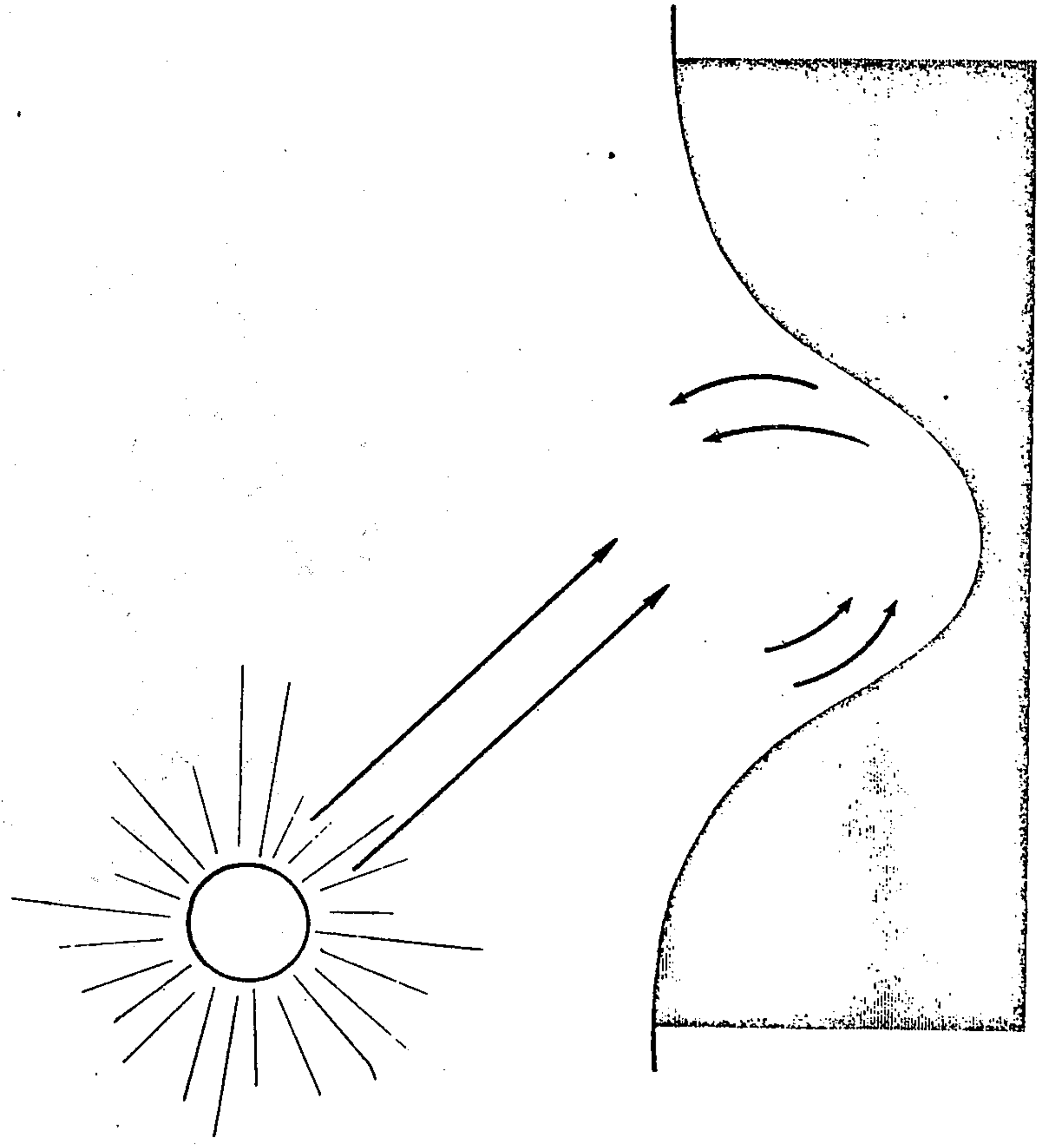
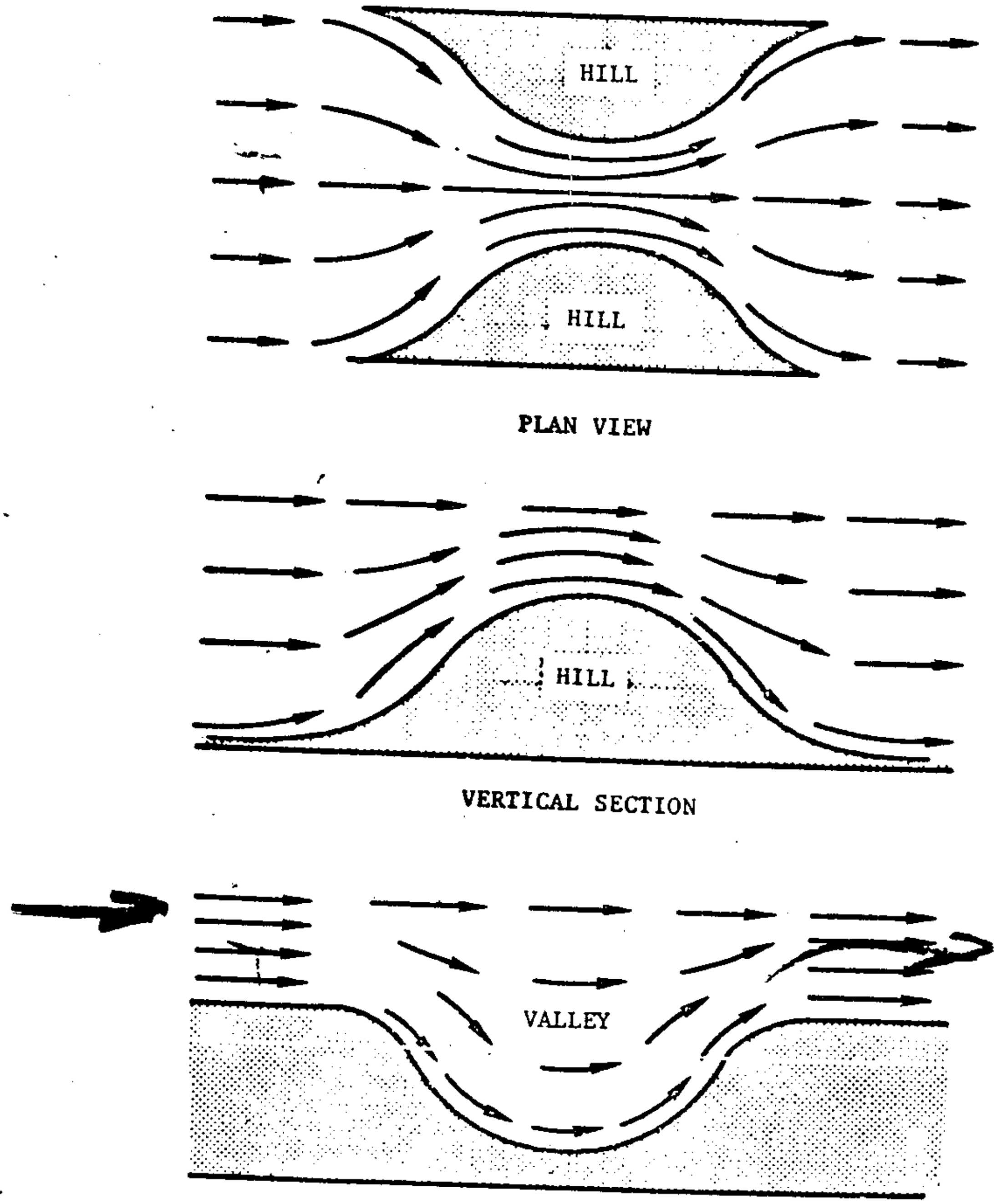
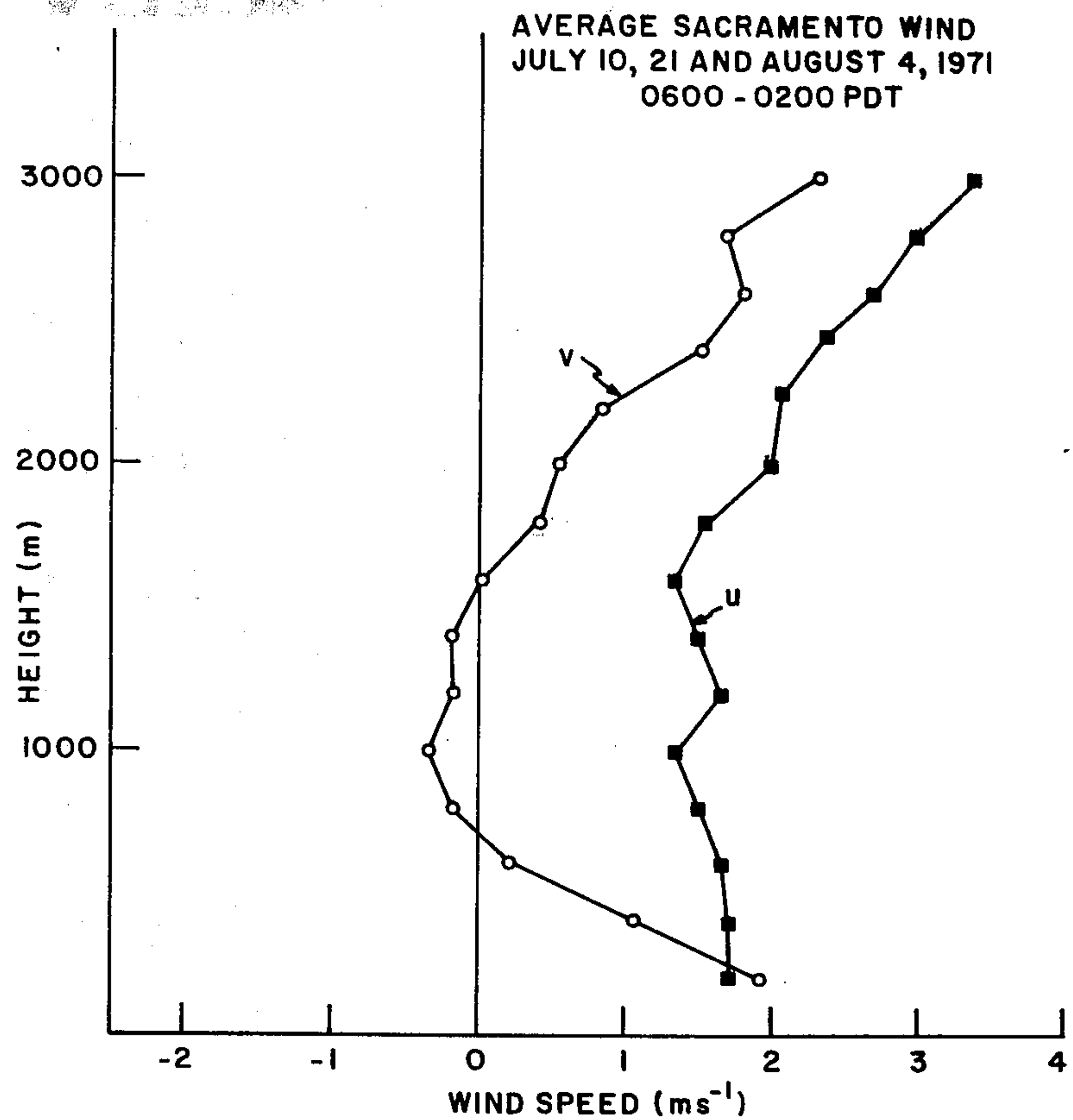


FIGURE 5-10



TOPOGRAPHY EFFECTS ON WIND

FIGURE 5-11



The overall average Sacramento Wind profile for July 10, 21 and August 4, 1971 between the hours of 0600 - 0200 PDT.

Figure 5-12

VII. Introduction to Atmospheric Turbulence

Definition: Random fluctuations of wind velocities.

A. Types of Turbulence

1. Mechanical Turbulence

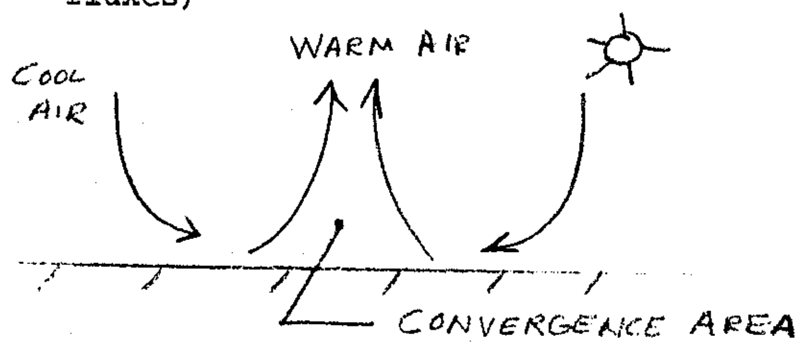
a. flow of air over obstruction, trees, houses, etc.

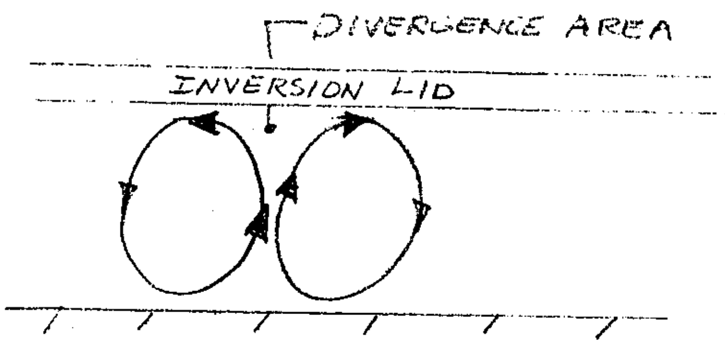
b. wind shear; function of surface roughness.

c. mixing cell - caused by the motion of moving vehicles; most dominating in microscale analysis.

2. Thermal Turbulence

a. caused by the heating of the ground surface by incoming radiation from the sun (heat fluxes)





3. Molecular Diffusion - caused by molecular motion of molecules.

   a. minor compared to mechanical and thermal turbulence.

NOTE: HIGH DEGREE OF TURBULENCE IS DESIRABLE TO DISPERSE AND DIFFUSE POLLUTANT CLOUDS RESULTING IN LOW CONCENTRATIONS.

TURBULENCE CAN BE CONSIDERED AS A MEASURE OF THE SPREAD OF A PLUME.

B. Environmental Lapse Rates

1. Dry adiabatic lapse rate or Neutral

   a. $\Delta h = \Delta U + \Delta W$; $\Delta h = 0$ (NO HEAT LOSS)
      $\gamma = -5.4°F/1000\ FT$ OR $\sim -1°C/100m$

   b. No vertical accelerations; thermal equilibrium.

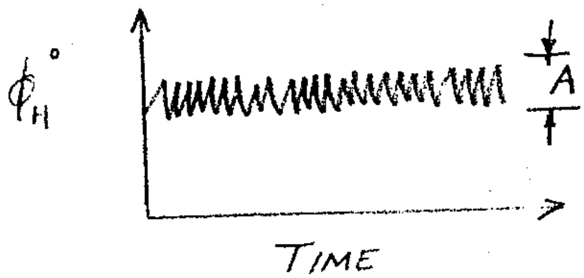
   c. Weather conditions - day or night condition.

      (1) high winds > 12 mph - strong winds dissipated heat buildup (Δh)

      (2) overcast skies - clouds reflect incoming radiation

      (3) change in maximum and minimum temperature for day < 10°F.

d. Wind trace

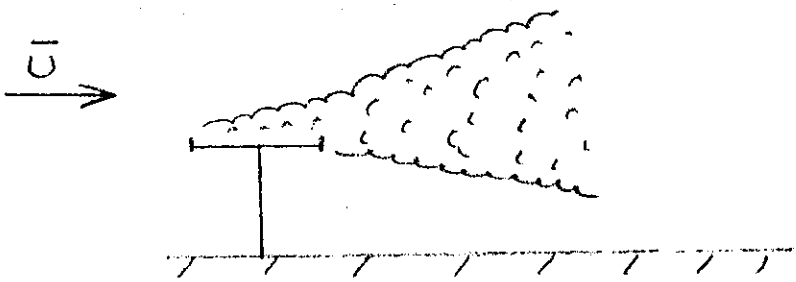


ϕ_H = HORIZONTAL WIND DIRECTION IN DEGREES

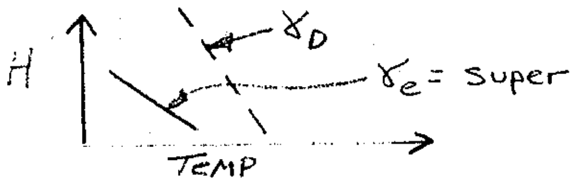
$30^{\circ} < A < 40^{\circ}$

e. Plume dispersion characteristic

(1) Coning - ideal for modeling purposes

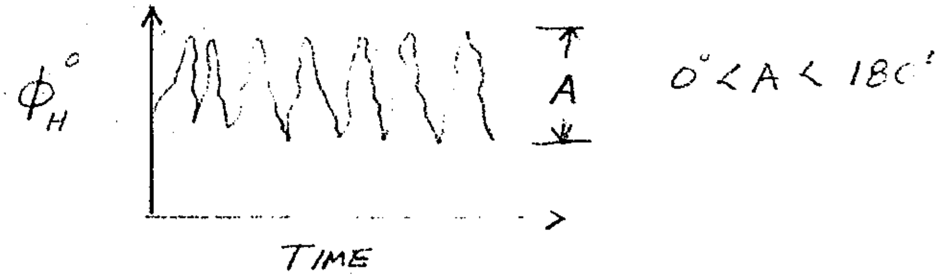


C. Superadiabatic lapse rate (air is cooler at a given height than corresponding neutral atmosphere).

1. 

2. large vertical accelerations
3. buoyant forces dominate
4. <u>unstable condition</u> - generally results in low pollutant concentrations.

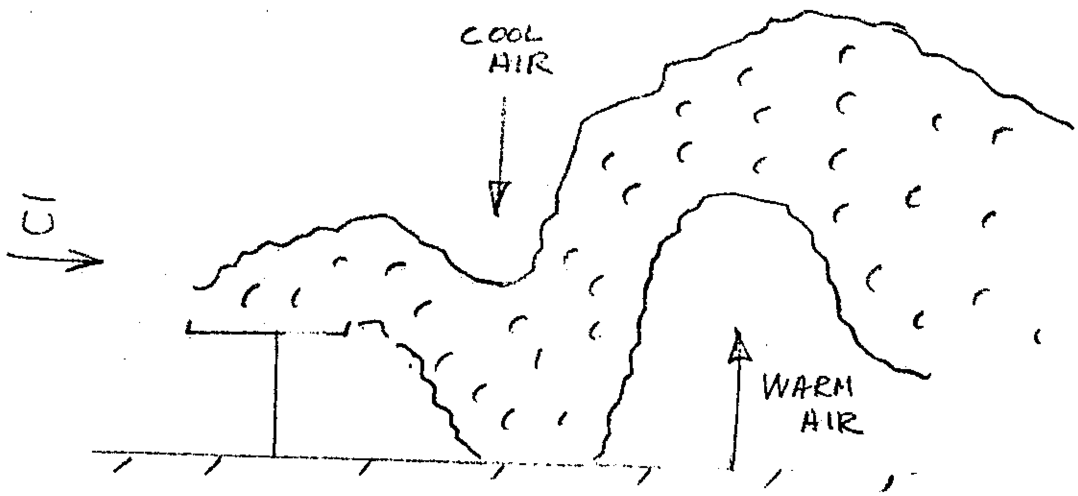
5. Wind trace



6. weather conditions - daytime

a. light winds, clear skies

7. Plume dispersion - looping plume



D. Inversion $\gamma_e = \frac{\partial T}{\partial z}$ = positive (Air is warmer at a given height than corresponding neutral atmosphere).

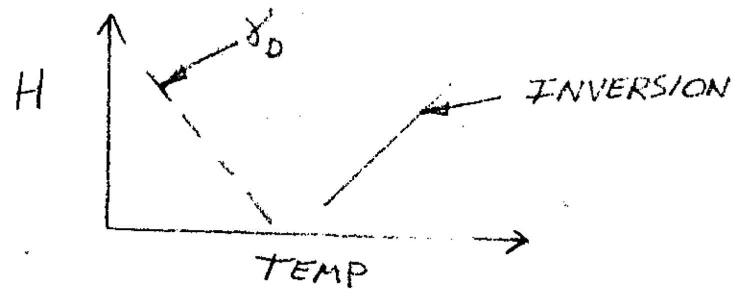
1. inversion - temperature increases with height

2. $\gamma_e > \gamma_D$ and is positive

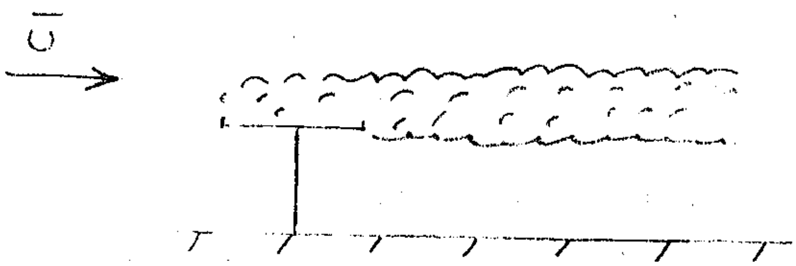
   Example: = +2°F/100/ft

3. stable conditions - negative acceleration, bad for air quality

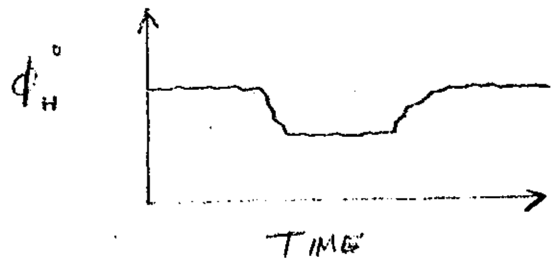
4. weather conditions: surface based inversion, nighttime and early morning, clear skies, light winds



5. plume dispersion - fanning plume



6. wind trace



square wave, very small fluctuations

$5^\circ < A < 10^\circ$

E. Effects of Surface Roughness on Turbulence

1. Land use vs. Mechanical and Thermal Turbulences

   a. flat open areas
   b. single dwelling
   c. industrial zoning

2. Thermal Conductivities

   a. Natural
   b. Man-made surface
   c. Changes or gradients in heat fluxes

3. Wind Shear - function of roughness and mechanical turbulence

4. See Figure 5-13

VI. Method to Estimate Atmospheric Turbulence

A. Pasquill - $\overline{u}$, cloud cover, day or night

B. Turner - modified Pasquill to include ceiling height, time of day and solar angle.

C. T's - measure lapse rates

D. Properties of turbulence controlled by $R_b = T/U^2$, indicates relative importance of stability effects (in creating or suppressing turbulence) and generation of mechanical turbulence.

E. Richardson Number, Monin-Obukhov length - further research required for transportation applications.

VII. Classification of <u>Surface</u> <u>Atmospheric</u> <u>Turbulence</u>

A. Pasquill Classifications, function of

1. season of year
2. time of day
3. insolation - solar geometry
4. wind speed
5. cloud cover
6. ceiling height

B. Classifications surface stability:

A = extremely unstable
B = unstable
C = slightly unstable
D = neutral
E = slightly stable
F = stable

C. General classification

A, B = unstable (superadiabatic)
C, D = neutral (dry adiabatic)
E, F = stable (subadiatic and inversion)

D. Pasquill Stability Classes Related to Air Quality

1. <u>Microscale</u>

A, B – generally favorable; low concentrations; C, D – buoyant or inertial forces dominate the dispersion.

E, F – unfavorable; high concentrations; very little turbulence, surface based inversion.

2. <u>Mesoscale</u> (assuming elevated inversion)

A, B – light winds, poor ventilation, high secondary pollutant concentrations.

C, D – strong winds, good ventilation; low concnetrations.

E, F – light winds, surface based inversion, poor ventilation, high primary pollutant concentrations.

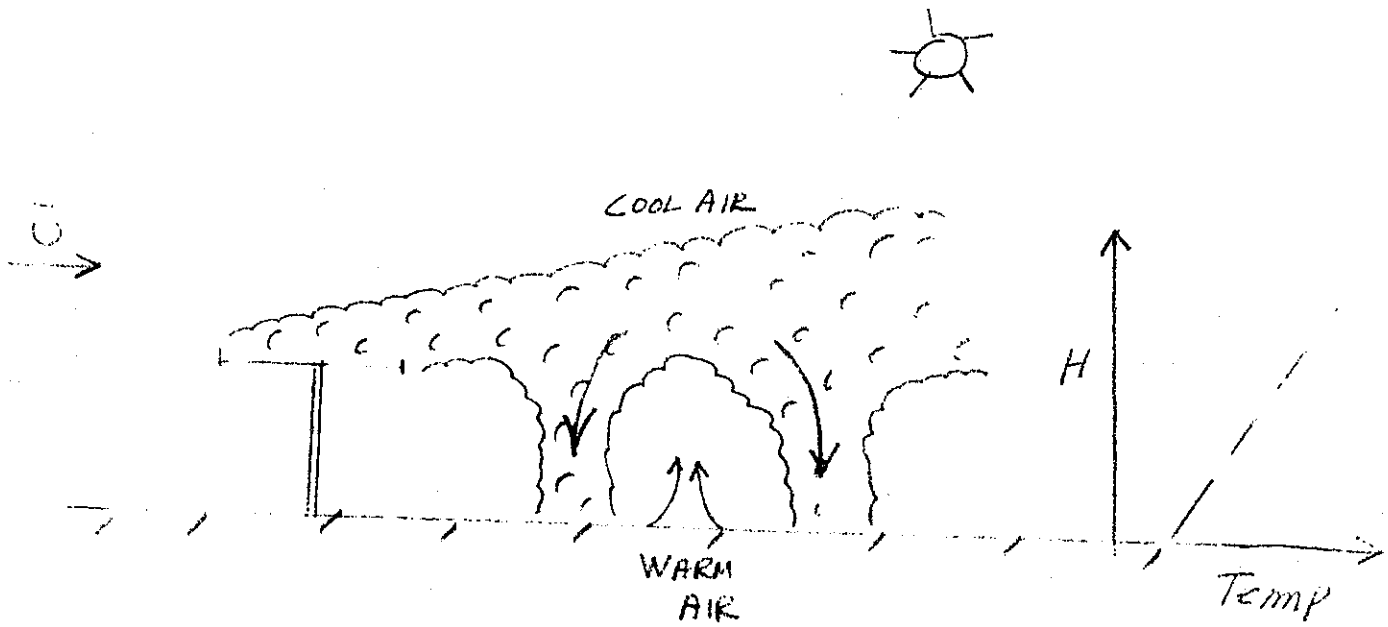
E. Plume Dispersion Characteristics According to Pasquill Stability Classifications:

1. Stability Class A-B (Unstable)
   a. looping plume

2. Stability Class C-D (Neutral)
   a. coning plume

3. Stability Class E-F (Stable)
   a. fanning plume

F. Fumigation - breakup of a morning surface based inversion caused by thermal heating of surface of earth.



PASQUILL STABILITY CLASSES

Surface Wind Speed (m/sec)	Daytime Insolation Strong	Daytime Insolation Moderate	Daytime Insolation Slight	Night Thinly Overcast or 4/8 Low Cloud	Night 3/8 Cloud
2	A	A-B	B	--	--
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

Maximum Insolation For California

Month	Insolation
Jan, Feb, Mar, April	Moderate
May, June, July, Aug	Strong
Sept, Oct, Nov	Moderate
Dec	Slight

The stability Category D should be assumed for overcast conditions during day or night.

H. Richardson Number (R_i)

1. General Equation See Figure 5-14
2. Characteristics of R_i - See Figure 5-15
3. Turner Stability Categories as a function of R_i - See Figure 5-16

4. Field measurements to calculate R_i - See Figure 5-17

I. Plume Dispersion Characteristics as a Function of Surface Stability

1. Elevated source - See Figure 5-18
2. Highway Sources - See Figure 5-19

J. Diurnal Variation of Meteorological Variables

1. Surface lapse rates - See Figures 5-20, 21
2. Urban vs. rural lapse rates - See Figure 5-22
3. Horizontal and vertical wind directions - See Figure 5-23, 24
4. Turbulence vs R_i - See Figure 5-25

K. Summary of Lapse Rates

1. Superadiabatic - unstable
2. Neutral or dry adsabatic
3. Subadiabatic - slightly stable
4. Isothermal - slightly stable
5. Inversion - stable
6. See Figures 5-26 through 5-28

TURBULENT MIXING CONTROLLED BY ATMOSPHERIC CONDITIONS

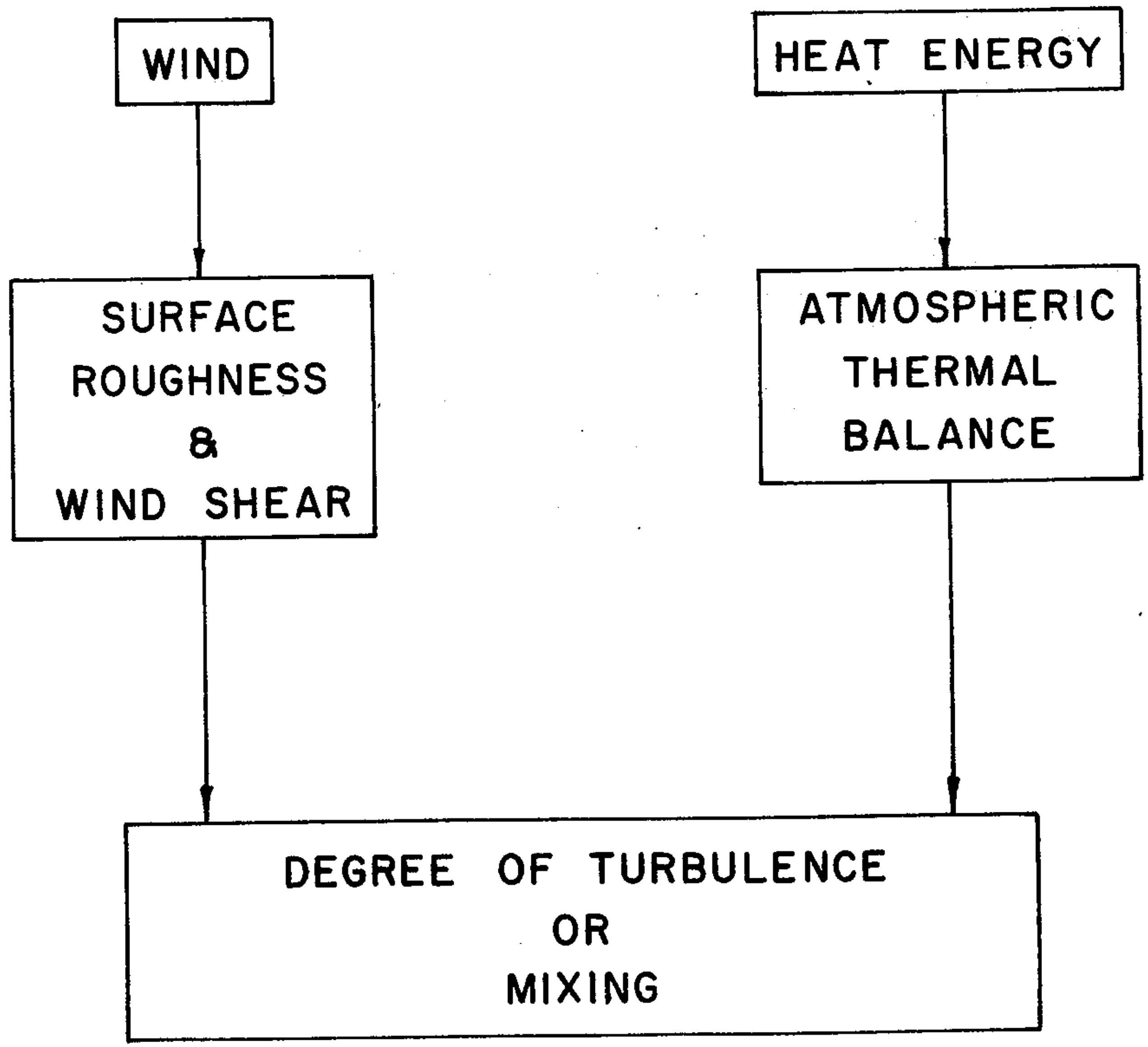


FIGURE 5-13

CHARACTERISTICS OF THE RICHARDSON NUMBER

Ri	IMPORTANT PARAMETERS	PLUME TYPE
LARGE (−)	CONVECTION	LOOPING
SMALL (−)	SOME CONVECTION	WEAK LOOPING
0	MECHANICAL	CONING
SMALL (+)	DAMPED MECHANICAL EDDIES	WEAK CONING
LARGE (+)	NO VERTICAL TURBULENCE	FANNING

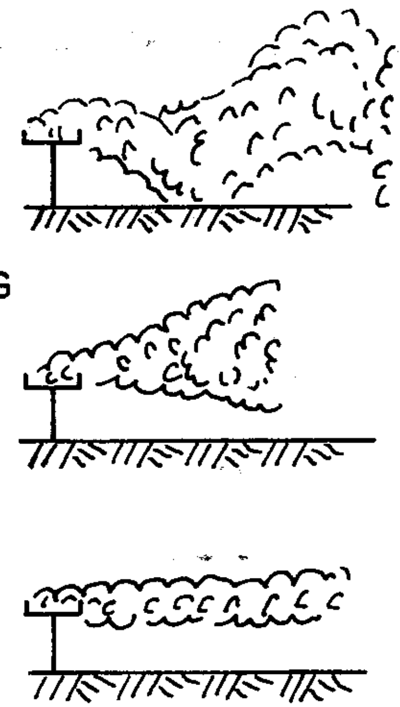


FIGURE 5-15

KEY TO STABILITY CATEGORIES
AS FUNCTION OF RICHARDSON NUMBER

SURFACE WIND SPEED AT (10m) M/SEC	DAY: INCOMING SOLAR RADIATION STRONG	DAY: INCOMING SOLAR RADIATION MODERATE	DAY: INCOMING SOLAR RADIATION SLIGHT	NIGHT: THINLY ≥OVERCAST 4/8 COVER	NIGHT: $\leq \frac{3}{8}$
< 2	A	B	B		
2 - 3	B	B	C	E	F
3 - 5	B	C	C	D	E
5 - 6	C	D	D	D	D
> 6	C	D	D	D	D

Ri<0   Ri=0   Ri>0

FIGURE 5-16

RICHARDSON NUMBER

$$Ri = \frac{\frac{g}{T}(\gamma_D - \gamma)}{\left(\frac{\delta u}{\delta z}\right)^2}$$

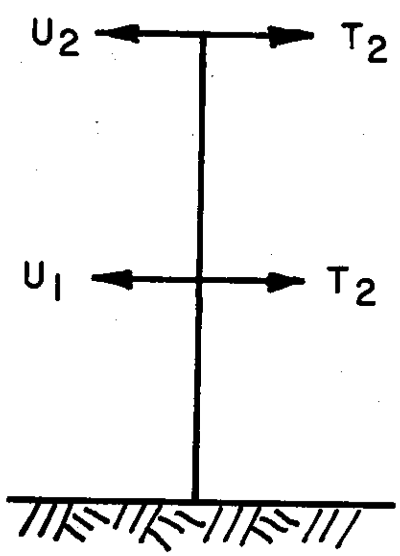
g = GRAVITY
T = TEMPERATURE
γ_D = DRY ADIABATIC LAPSE RATE
γ = ENVIRONMENTAL LAPSE RATE
$\left(\frac{\delta u}{\delta z}\right)$ = WIND SHEAR

$Ri < 0$ UNSTABLE
$Ri = 0$ NEUTRAL
$Ri > 0$ STABLE

THE Ri NO. IS A DIMENSIONLESS NUMBER THAT IS A MEASURE OF ATMOSPHERIC STABILITY.

FIGURE 5-14

FIELD MEASUREMENTS REQUIRED TO CALCULATE RICHARDSON NUMBER



60 FOOT TOWER WITH U_2 & T_2 AT 60' AND U_1 & T_1 AT 20'

δ's = f(SURFACE ROUGHNESS, Ri)

FIGURE 5-17

PLUME DISPERSION CHARACTERISTICS AS FUNCTION OF SURFACE STABILITY

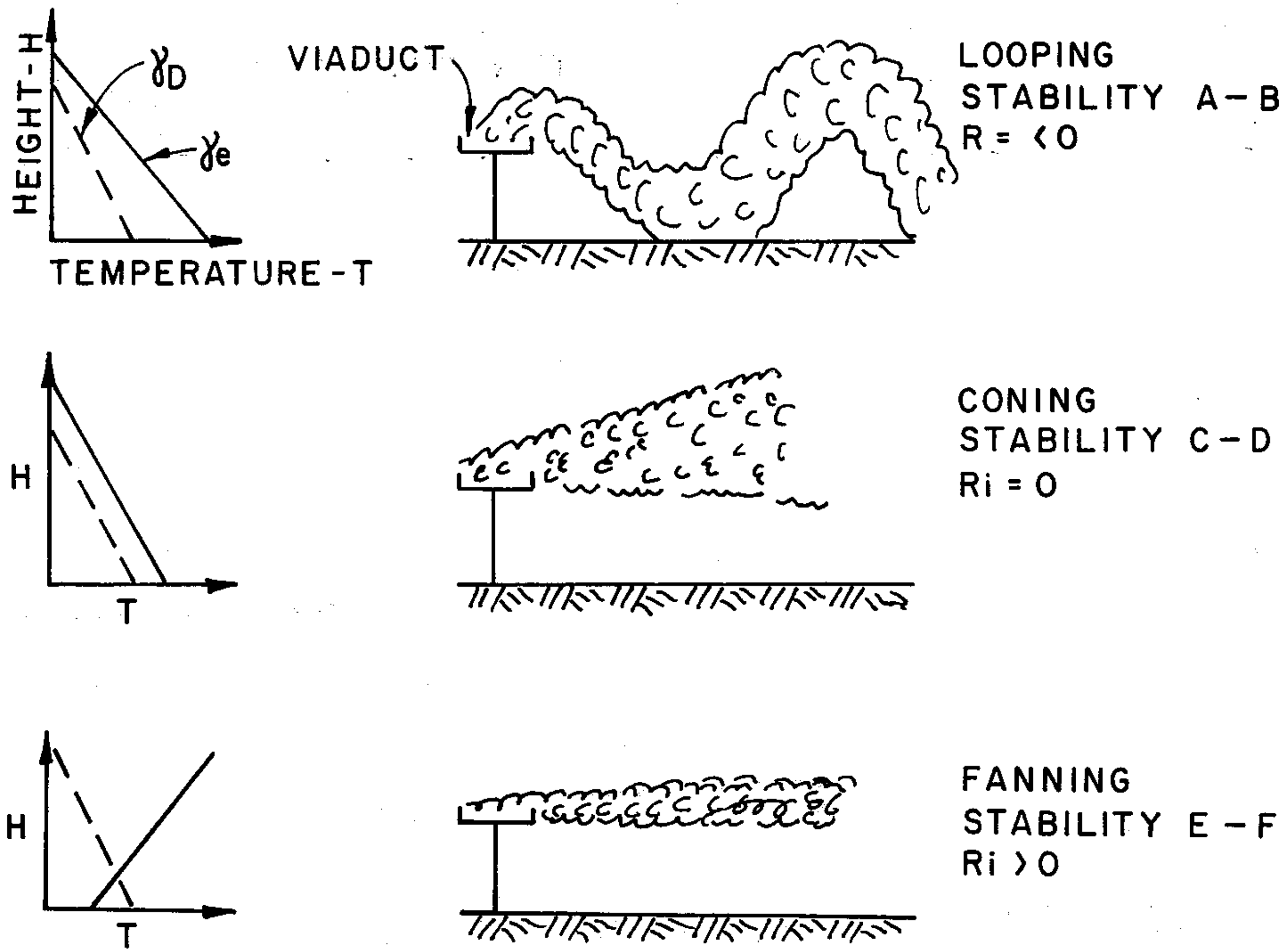


FIGURE 5-18

PLUME DISPERSION CHARACTERISTICS
AS FUNCTION OF SURFACE STABILITY

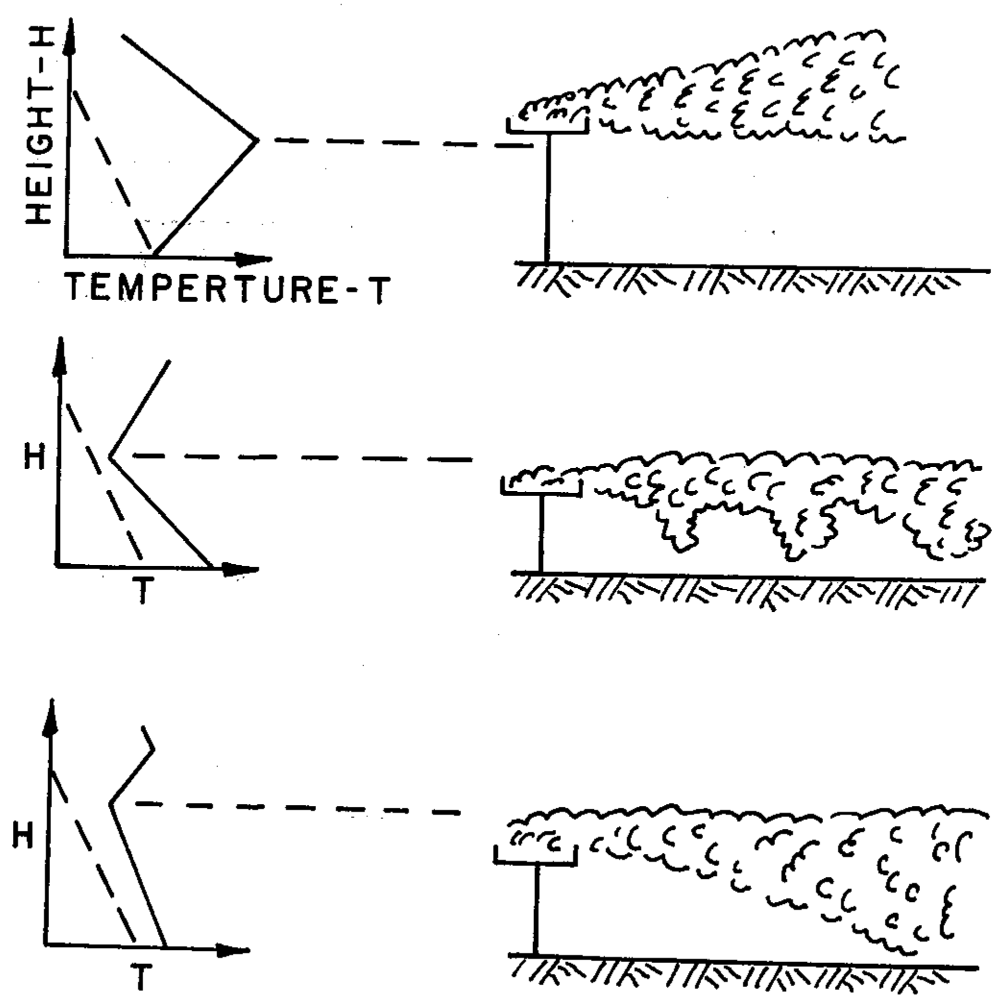
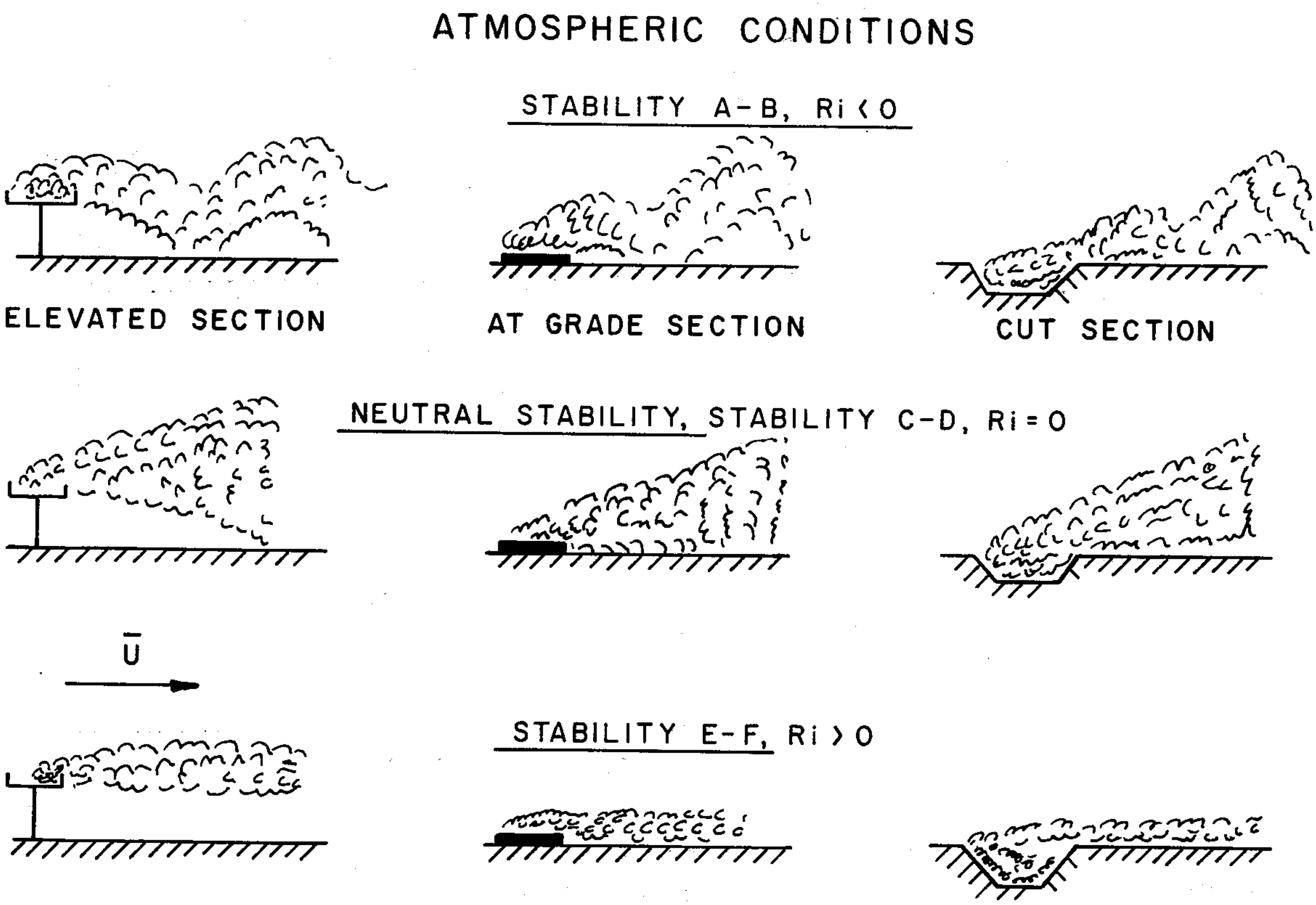


FIGURE 5-18a



PLUME DISPERSION CHARACTARISTICS FOR HIGHWAY DESIGNS

FIGURE 5-19

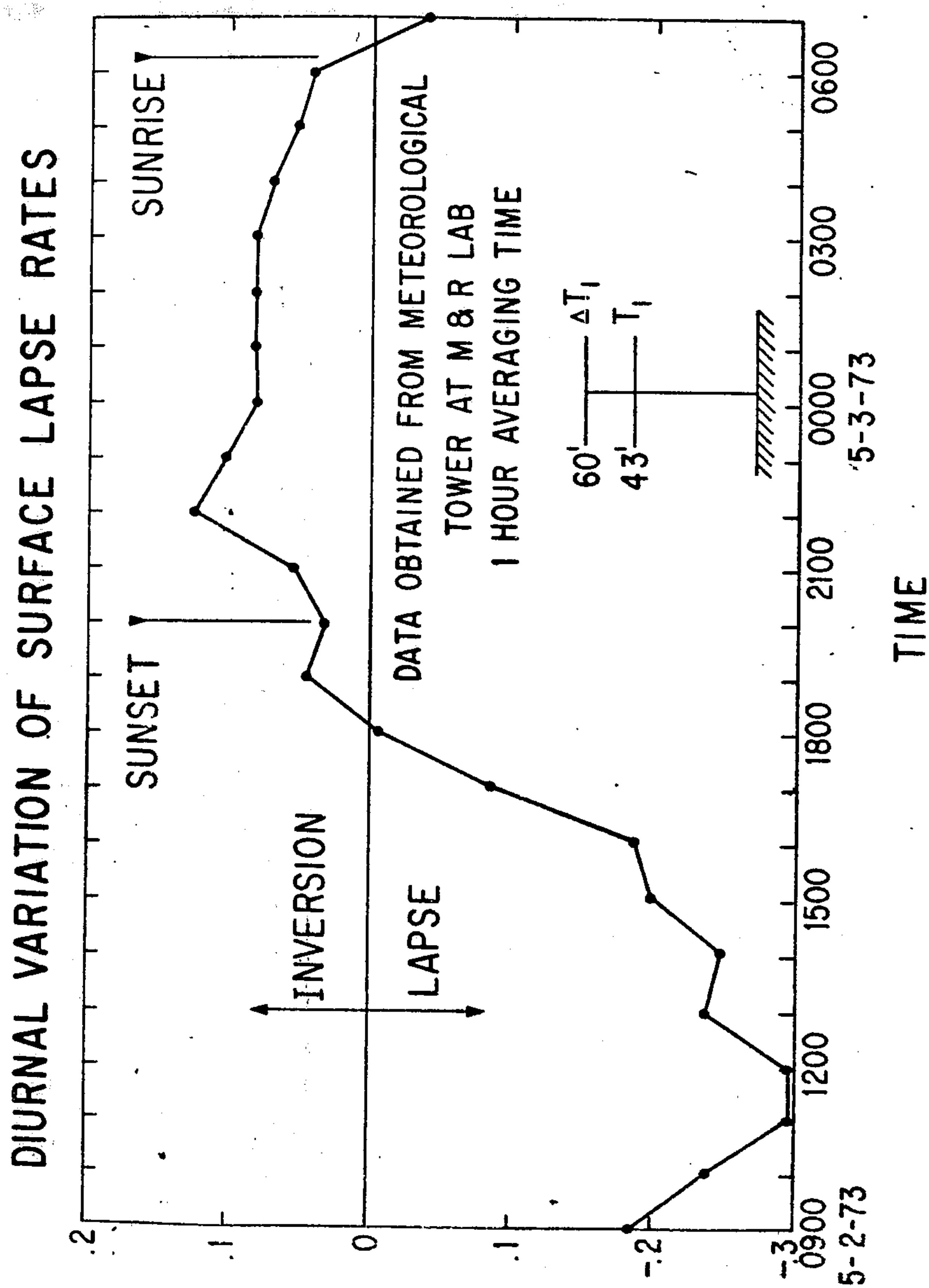
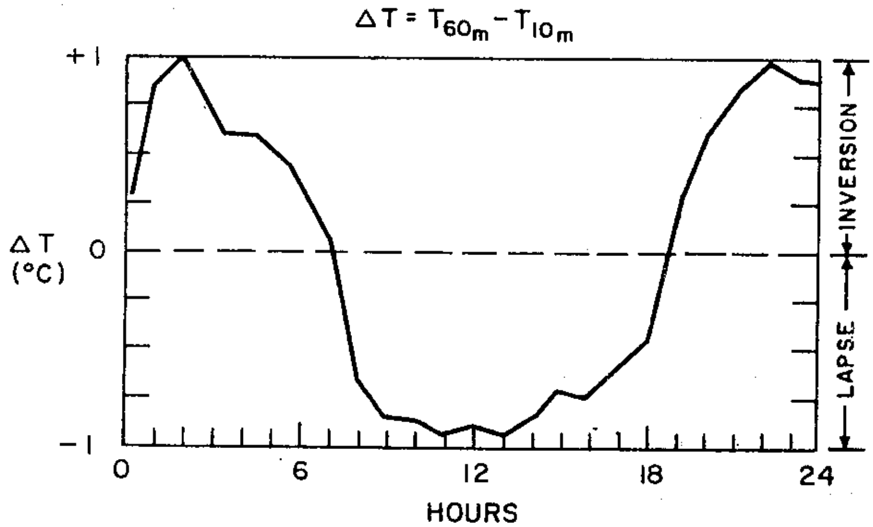

DIURNAL VARIATION OF SURFACE LAPSE RATES
SUNRISE
SUNSET
INVERSION
LAPSE
DATA OBTAINED FROM METEOROLOGICAL
TOWER AT M & R LAB
1 HOUR AVERAGING TIME
60'
43'
ΔT_1
T_1
.2
.1
0
-.1
-.2
-.3
0900
1200
1500
1800
2100
0000
0300
0600
5-2-73
5-3-73
TIME

FIGURE 5-20



SOURCE: "Prediction of the Dispersion of Airborne Effluent" 1968 (ASME)

DIURNAL VARIATION OF LAPSE RATE
OPEN COUNTRY

FIGURE 5-21

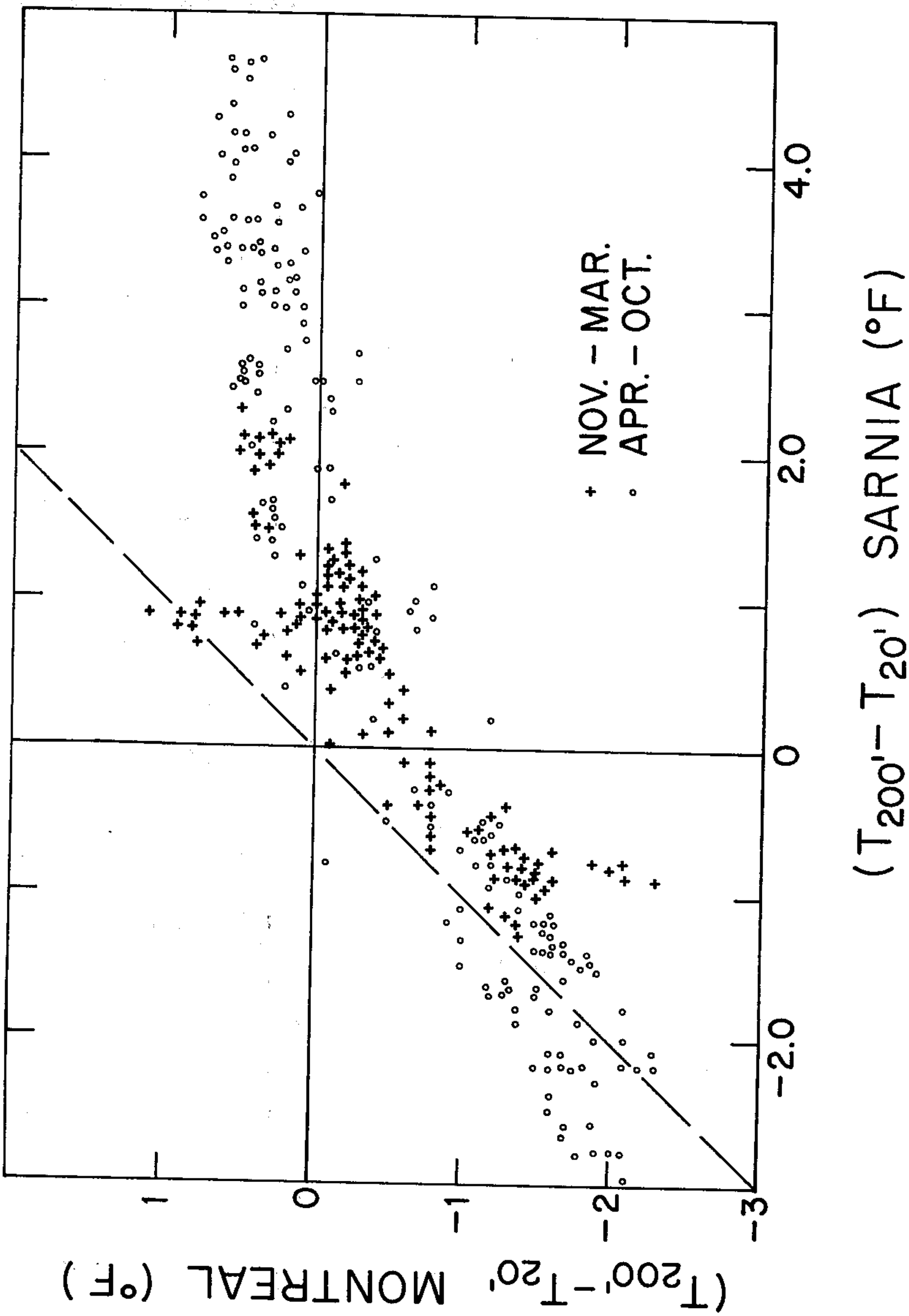

+ NOV. - MAR.
∘ APR. - OCT.
(T200' − T20') SARNIA (°F)
(T200' − T20') MONTREAL (°F)
4.0
2.0
0
−2.0
1
0
−1
−2
−3

FIGURE 5-22

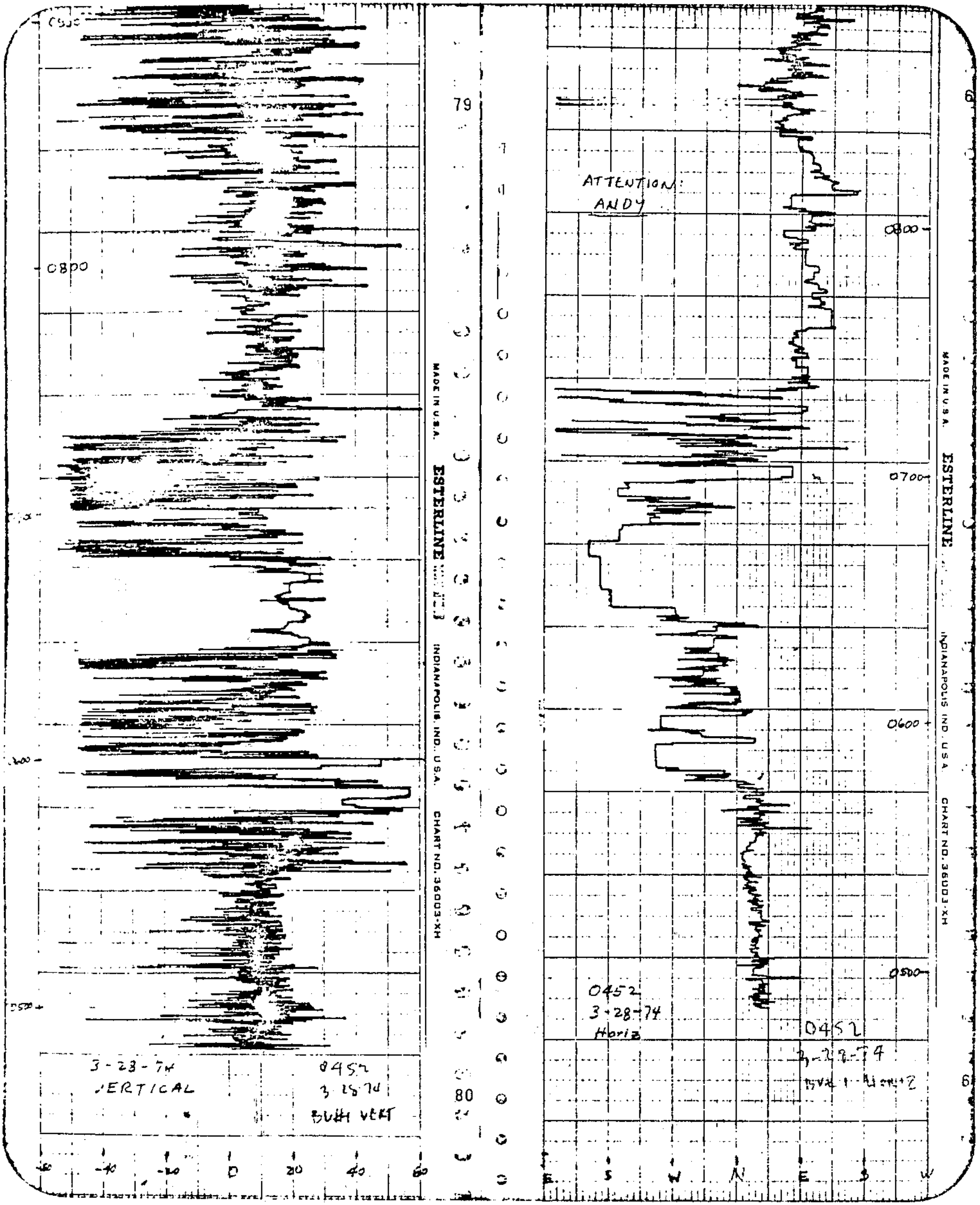


FIGURE 5-23 & 24

VERTICAL TURBULENCE VS RICHARDSON NO.

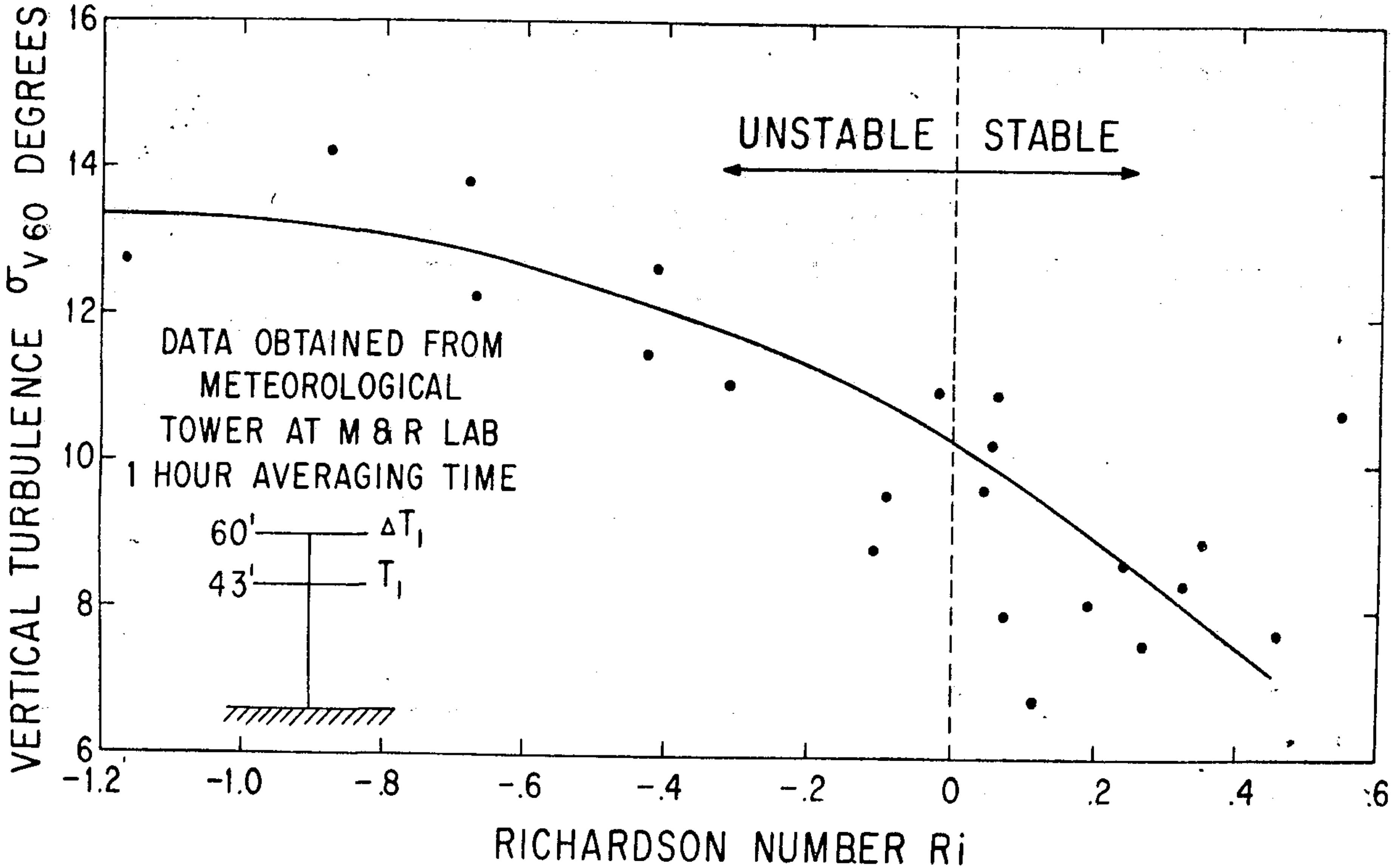
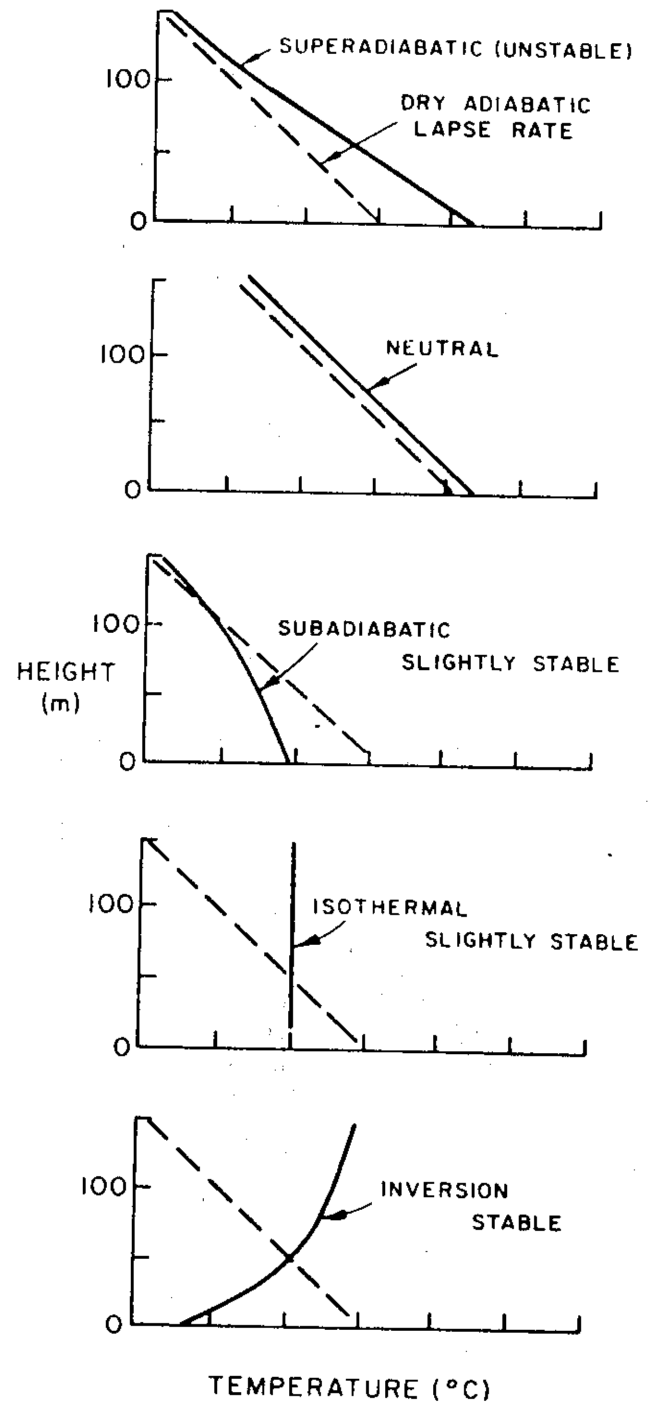


FIGURE 5-25



SOURCE: "Prediction of the Dispersion of Airborne Effluent" 1968 (ASME)

TYPICAL ENVIRONMENTAL LAPSE RATES

Figure A-26

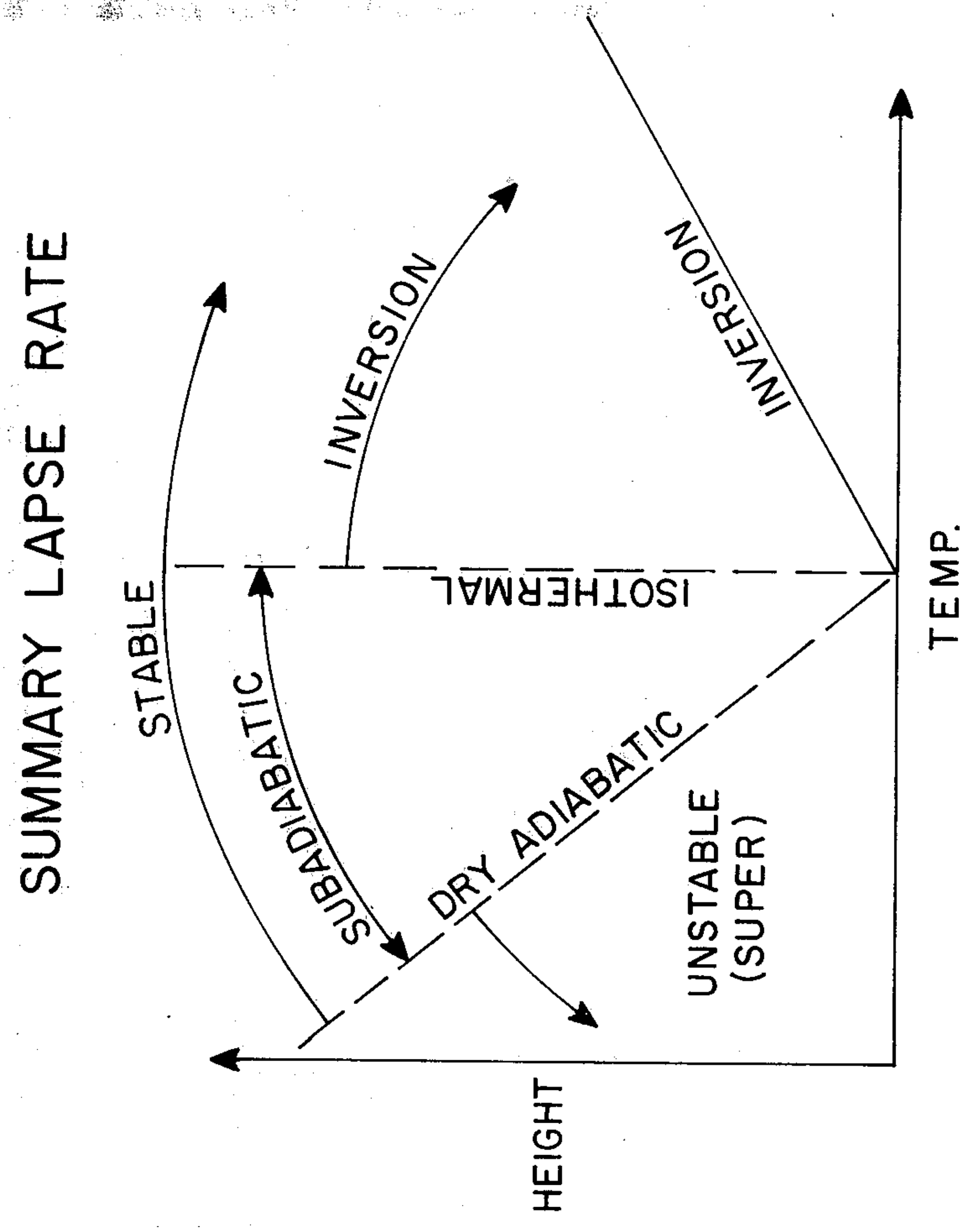

SUMMARY LAPSE RATE
STABLE
SUBADIABATIC
INVERSION
INVERSION
ISOTHERMAL
DRY ADIABATIC
UNSTABLE
(SUPER)
TEMP.
HEIGHT

FIGURE 5-27

LAPSE RATE CHARACTERISTICS

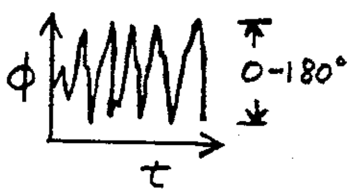
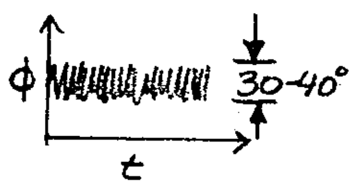
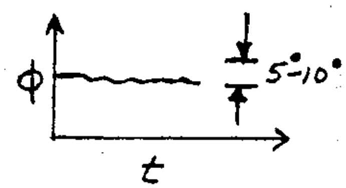
	Unstable A-B	Neutral C-D	Stable E-F
Meteorological Conditions	Day time, mid-day, light winds, clear skies	Day or night, Strong winds or cloudy or overcast skies	Late evening, night & early mornings, light winds & clear skies
Lapse Rate	$\gamma_e < \gamma_D \left(\frac{-5.4°F}{1000 ft}\right)$	$\gamma_e \sim \gamma_D$	$\gamma_e > \gamma_D$
Plume	Looping	Coning	Fanning
Wind Trace			

FIGURE 5-28

BASIC SUMMARY METEOROLOGICAL REQUIREMENTS

1. Wind speed and direction

2. Wind changes with horizontal and vertical distance from source.

3. Wind changes due to topographic features (hills, valleys, lakes, etc.)

4. Wind changes with time (daily and seasonal variations).

5. Turbulence in the air mass for mixing in horizontal and vertical.

6. Turbulence changes with weather conditions.

7. Turbulence changes with topographic conditions (surface roughness).

8. Separation of mechanical and thermal turbulence.

VIII. Aerodynamic Effects of Air Flow Affecting Air Quality

A. Mean Flow Around a Cubical Building

1. Background flow
   a. Air flow separation
2. Displacement flow
3. Wake region
4. Cavity zone
5. Velocity profiles
6. See Figure 6 Meteorology Manual
7. Location of Wind Stations
   a. top and corner of buildings
   b. cavity zone
   c. wake region

B. Air Flow Over Fills

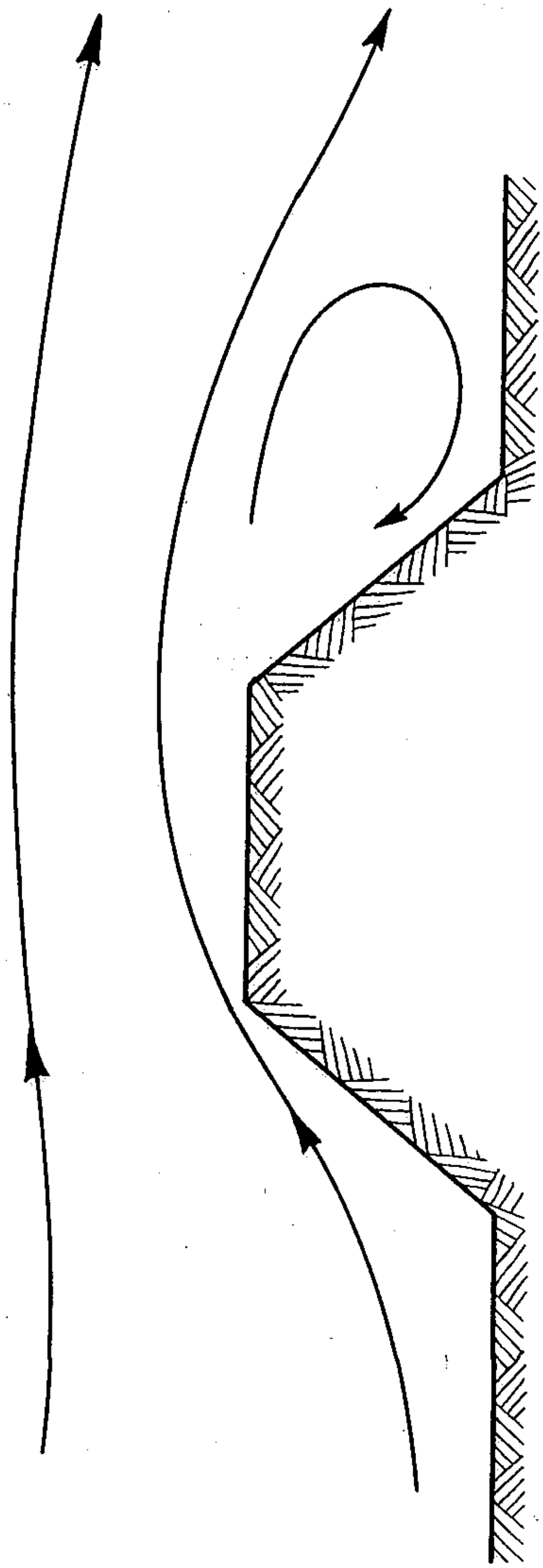
1. convergence
2. Separation
3. Cavity zone
   a. Sink for gaseous pollutants
   b. Entrainment of particulate matter
4. See Figure 5-29

C. Air Flow Over Cut Sections

1. Separation
2. Pollutant Potential
   a. restrict horizontal dispersion
   b. confine heavy particulate matter
3. See Figure 5-30

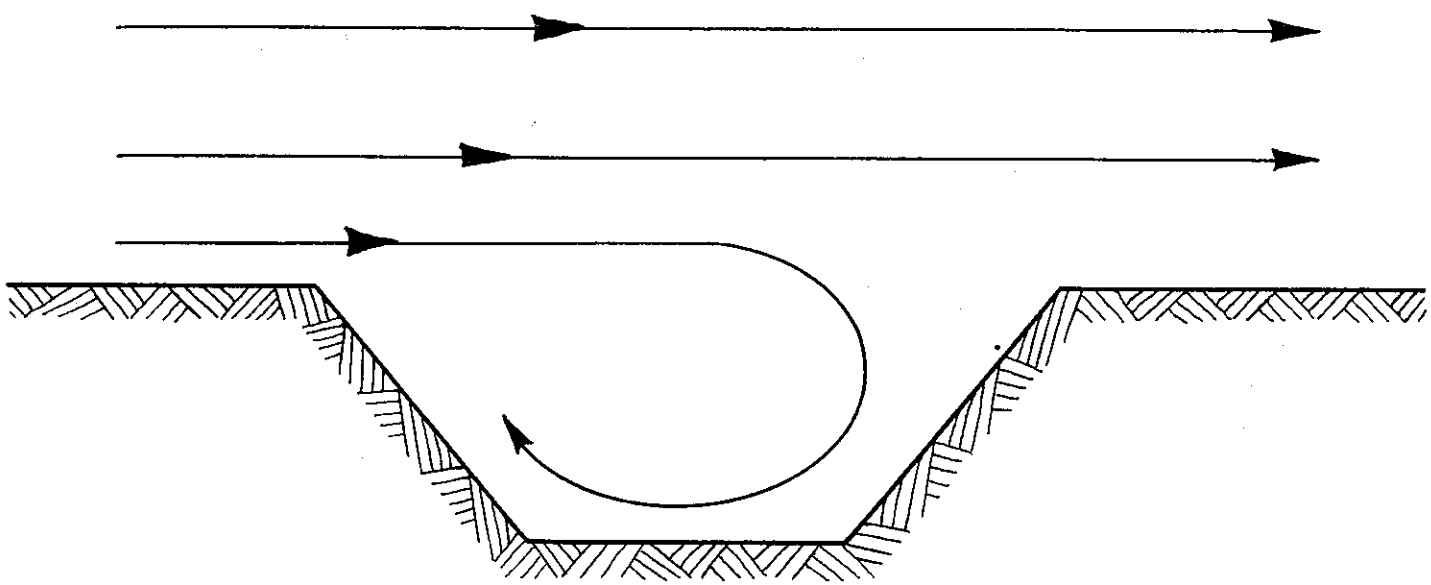
D. Highway Designs Affecting Agricultural Production

1. Highway fill
2. Dam cool air
3. Citrus orchards



AIR FLOW OVER FILL SECTION FOR CROSSWIND

FIGURE 5-29



AIR FLOW IN CUT SECTION FOR CROSSWIND

FIGURE 5 30

E. Estimates of Length of Cavity Zone

1. Cubical building
2. Highway fill
3. See Figure 7 in Meteorology Manual

F. Downwind Aerodynamic Effects on Dispersion of Pollutants From Highway Line Sources

1. Viaduct Section - See Figures 8 and 9 in Meteorology Manual.
2. Deep wide valley - See Figure 10 Meteorology Manual.
3. Winds parallel to Valley Axis - See Figure 11 Meteorology Manual.
4. Land Forms - See Figure 12 Meteorology Manual.

IX. Urban Heat Island

A. Definition: Difference of temperature between rural and city environments

Range: 2-5°F

Maximum: San Francisco 10°C from CBD to Park

B. Possible Cause

1. Combustion and dissipation of other energies

a. Motor Vehicle
b. Industrial
c. Domestic

2. Blanketing effect of urban atmospheric pollution.

a. Pollution cloud at night absorbs and re-emits thermal radiation from the city resulting in large nocturnal temperature excesses.

3. Little evaporation or plant transpiration in city.

a. $R_n = LE + H + G$ (Energy Balance)

Where R_n = net radiation

H = sensible heat flux

LE = latent heat flux

G = soil heat flux

Solar radiation must go into heating the city streets, buildings, etc.

4. Man-made materials (concrete and asphalts) surfaces have large heat capacities and conductivities.

a. City can absorb large amounts of heat relative to rural soils during the day which becomes available at night for noctural radiation losses.

SUMMARY OF CAUSE:

In general these arguments or explanations suggest strongly that the urban heat island is a result of a complex set of interacting physical processes.

Characteristics of Urban Heat Island

1. Nighttime excess temperatures are the largest.

2. ΔT excess $\propto$ to city size

3. ΔT excess $\propto \frac{1}{[illegible]}$

C. Applications to Air Quality

1. Plume dispersion city vs. rural
See Figure 13 in Meteorology Manual

GROUP PROBLEM ON PLOTTING SURFACE STREAMLINES

X. Exposures of Surface Wind Systems

A. Need for criteria

1. Inconsistent exposure
   a. APCD
   b. Airports
   c. ARB
   d. Other sources

2. Difficult to compare data

B. Criteria Based on EPA Recommendations

1. Flat open areas
   a. See Figure 14 Meteorology Manual

2. Build-up areas
   a. See Figure 15 Meteorology Manual

3. General modification of criteria for urban areas

C. Wind Sensor Exposure on a Tower

1. Aerodynamic effects
2. Accurate measurements
3. See Figure 16 Meteorology Manual

D. Wind Sensor Exposure on a Stack

1. Aerodynamic effects - Von Karmen Vortices
2. Aerodynamic effect of sensor on telephone pole
3. See Figure 17 Meteorology Manual

E. Slides of Exposure of Meteorological Wind Stations

SECTION 6

REDUCTION OF METEOROLOGICAL DATA AND METEOROLOGICAL SURVEYS

I. Sources of Meteorological Data

A. Refer to Page 11 of Meteorology Manual

B. Collection of Meteorological Records

1. Minimum of 5 years
2. Pacific Standard Time vs. Local Time

II. Data Analysis

A. Time Periods to Analyze Meteorological Data

.Because the NAQS are based on one hour exposure times, predictions of air quality must be made on an hourly basis. Therefore, meteorological data must be reduced on - hourly basis.

1. The following should be considered when reducing meteorological data to describe a typical and bad day.

a. weekday traffic variations
b. weekend traffic variations
c. recreational traffic
d. holiday traffic
e. pollutant seasons - winter and summer
f. combination of above for source and meteorology

2. Guidelines For Time Periods

a. See Page 67 of Meteorology Manual

AT THIS POINT IN THE COURSE THE STUDENTS SHOULD BE ABLE TO ANSWER THE FOLLOWING:

1. Are yearly or monthly wind roses of value to predict air quality for a typical or bad day? Can any use be made of this information?

B. Computer Programs for Analyzing Aerometric Data

1. WIND2 - determine wind roses only

2. WNDROS - determine wind roses and stability distributions from data on magnetic tape.

3. STAR2 - determine wind roses and stability class distributions from raw data on punched cards.

C. Computer Outputs

1. Tabular wind rose - See Page 133 of Meteorology Manual.

a. Prevailing wind direction
b. Wind speed group
c. Calms - function of sensitivity of wind system.

2. Most probable and worst meteorological conditions.

a. See Pages 130 through 136 in Meteorology Manual.
b. Cluster of wind directions for Stability Class F.
c. High wind speed ($>$10 mph) or overcast skies for Stability Class D.
d. Light winds for Stability Class A.

III. Meteorological Surveys

See Pages 34 through 45 in Meteorology Manual for details.

A. Purpose

1. develop surface streamline lines
2. determine surface atmospheric stability conditions
3. describe the transport and diffusion of pollutants

B. Paper Study

1. Use of topographic map

C. Exposure of Existing Stations

D. Correlation Analysis to Reduce Sampling Time.

1. Data Base for prediction using regression analysis.

a. winter to winter
b. summer to summer
c. winter to summer

2. Variables to consider for correlation

   a. calibration
   b. response characteristics of wind speed and direction
   c. exposure
   d. maintenance
   e. averaging times - ten seconds vs. 1 hour

GROUP PROBLEM DESIGN METEOROLOGICAL SURVEY

WIND INSTRUMENTATION SURVEY

LOCATION : BY : DATE :

1. A. MANUFACTURER :

   B. MODEL NO. : C. NAME :

2. A. PARAMETER B. THRESHHOLD C. ACCURACY

   1. WIND SPEED :

   2. WIND DIRECTION :

3. MAINTENANCE SCHEDULE :

4. CALIBRATION SCHEDULE :

5. RECORDING INSTRUMENTS

   A. POWER SOURCE :

   B. AVERAGING TIMES :

   C. RECORDING METHOD :

   D. DATA HANDLING :

   E. PARAMETER/UNITS REPORTED

   F. CHART SPEED :

   G. SCALES :

   H. YEARS OF CONTINUOUS RECORD
      FOR INSTR. AT SAME LOCATION

6. EXPOSURE : A. OBSTRUCTIONS : B. TERRAIN :

   C. HEIGHT OF INSTRUMENTS :

7. PHOTOS : PANORAMICS AND 'CLOSE-UPS'

8. COMMENTARY : BY OF PHONE

SECTION 7

AIR QUALITY MONITORING AND ANALYSIS

I. Purpose of an Ambient Air Quality Study

A. Broad Purpose - Characterize Spatial and Temporal Air Quality

B. Specifically

1. Characterize existing levels for subjective comparison and with respect to the Air Quality Standards. The comparison with the Air Quality Standards would require that mathematical model predictions be added to the existing levels.

2. Provide a data base for planning in Future Analysis.
3. Model validations.
4. Analyze source strength preduction.
5. Predict or estimate future ambient air quality
6. Identify pollutant transport.
7. Construct time history of adverse days.
8. Estimate pollutant burden.
9. Locate problem, or hot spot, areas.
10. Correlation of existing data.

II. Spatial Location of Data Points

A. The sampling location depends upon the main purpose of the study as outlined above. When we talk about locating the air sampling points we are really talking about planning the Ambient Air Quality Study.

B. Important Determining Factors

1. Microscale considerations - where are the people? Patterns of human habitation and use of immediate facilities must be determined.

2. Mesoscale consideration - the air quality sampling points may have to be chosen to represent air quality for the community at large or for the air basin. This means that the average levels are wanted.

3. Sensitive receptors.

4. Topography - Topographic effects on meteorology stemming from areas of homogeneous land use patterns (roughness) must be considered.

5. Meteorology - Stagnant areas, wind flow patterns, wind directions, and wind velocities.

6. Point and line sources - These may distort the mesoscale picture if sampling points are located within their influence, but it may be necessary to locate sampling points within the influence of existing sources for microscale analysis.

7. Highway Design Features - Features such as major interchanges, peak traffic areas, potential bottleneck areas, and various types of cross-section design may create special situations which might influence the location of air quality sampling sites.

8. Fill areas which may act as dams - For nighttime situations where the downhill flow of the denser air and entrapped pollutants may cause a "cold air" lake, it may be desirable to establish an air quality sampling site.

9. Politically "sensitive" locations - Areas that are of particular concern to the local community, as evidenced by newspaper articles and communications from concerned citizen groups, should be sampled even when the technical considerations may rule otherwise.

III. Sampling Times - Temporal Data Distribution

A. Sampling times are dictated not only by purpose but also by typical and worst case meteorology and by the variation in source strength.

B. Factors to Consider

1. Seasonal aspect - The sampling for oxidant should be concentrated in late spring, summer, and early fall. Oxidant samples during other periods of the year can be taken less frequently. Carbon monoxide should be sampled primarily during the late fall or winter, since historically, the maximum concentrations are found to exist at that time.

2. Meteorology - Various meteorological regimes as well as worst case and most typical cases should be considered. Various inversion heights should also be a matter of consideration.

3. Traffic Patterns (Source Strength Variation), particularly with respect to peaks, are important.

4. The characteristics of point source operation - Factories, power stations, and similar installations may vary their output depending upon the time of day. These variations may be important.

5. Combinations of the above factors.

6. The averaging times called out in the standards, as well as, in the case of hydrocarbons, the specific sampling time will be important.

7. Receptor activity - It is more important to sample, for instances, near a school during the periods when the students may be expected to be in attendance, than to sample in the late afternoon when there are no receptors around.

IV. Kind of Pollutants for Air Quality Study

A. Primary - CO, HC, NO_x, Particulates, Sulfates

B. Secondary - O_3

C. Ambient Air Quality Standards

1. Federal
2. State

V. Uses of Ambient Air Quality Data

A. Characterize existing levels

1. Baseline or frame of reference
2. Additive to air quality models to compare to the ambient air quality standards.

   a. Microscale - See Figure 7-1
   b. Mesoscale or regional - See Figure 7-2

3. Required for Regional Photochemical Models on a temporal and spatial bases.

B. Data Base for Planning

1. Pollutant contours (isopleths) for typical meteorological conditions and stagnant areas.

2. Model verification

   a. Line Source
   b. Regional

3. Predict Future Air Quality

4. Evaluate Pollutant Transport

   a. Dual Peak Analysis - See Figure 7-3
   b. Surface wind Analysis - See Figure 7-4

5. Time History of Adverse Days

   a. See Figure 7-5

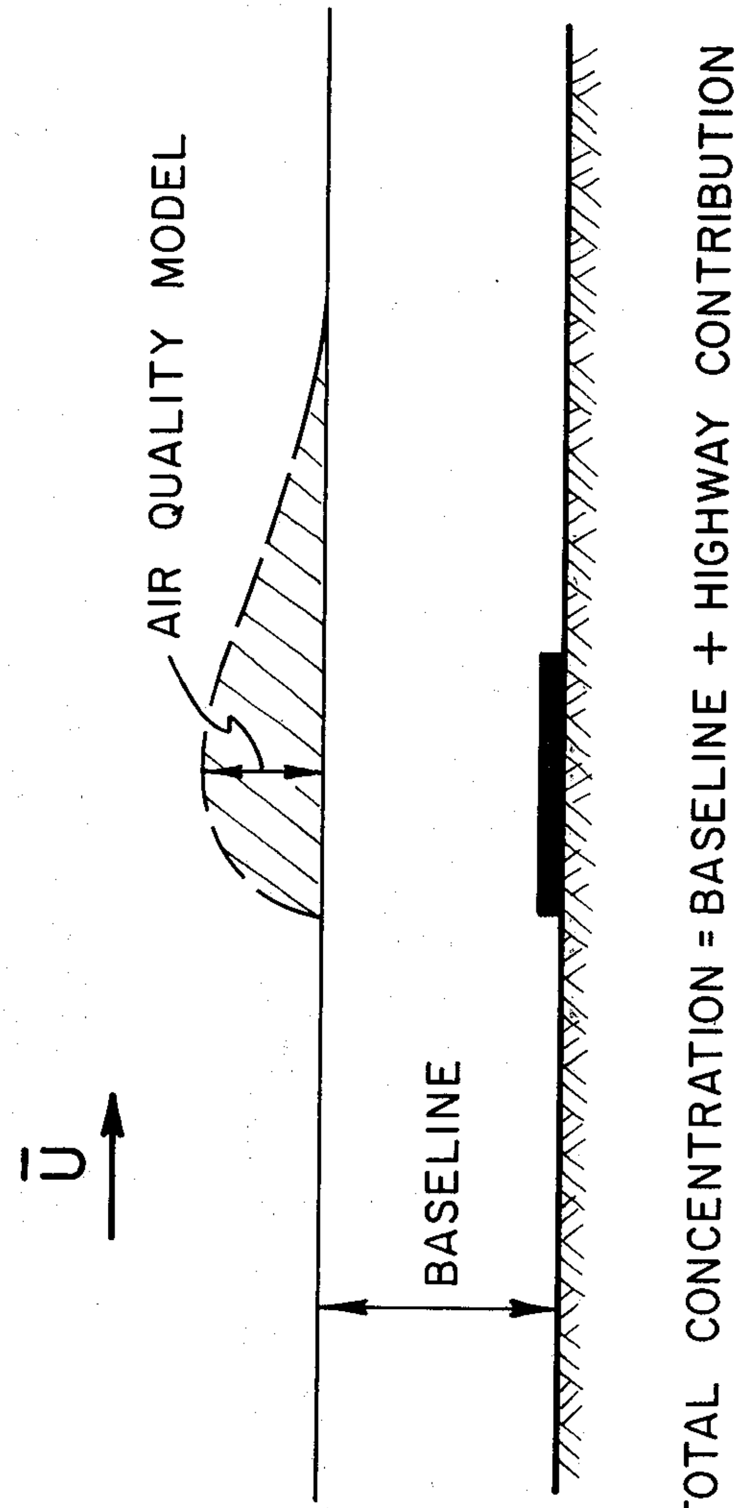

AIR QUALITY MODEL
$\bar{U}$
BASELINE
TOTAL CONCENTRATION = BASELINE + HIGHWAY CONTRIBUTION

FIGURE 7-1

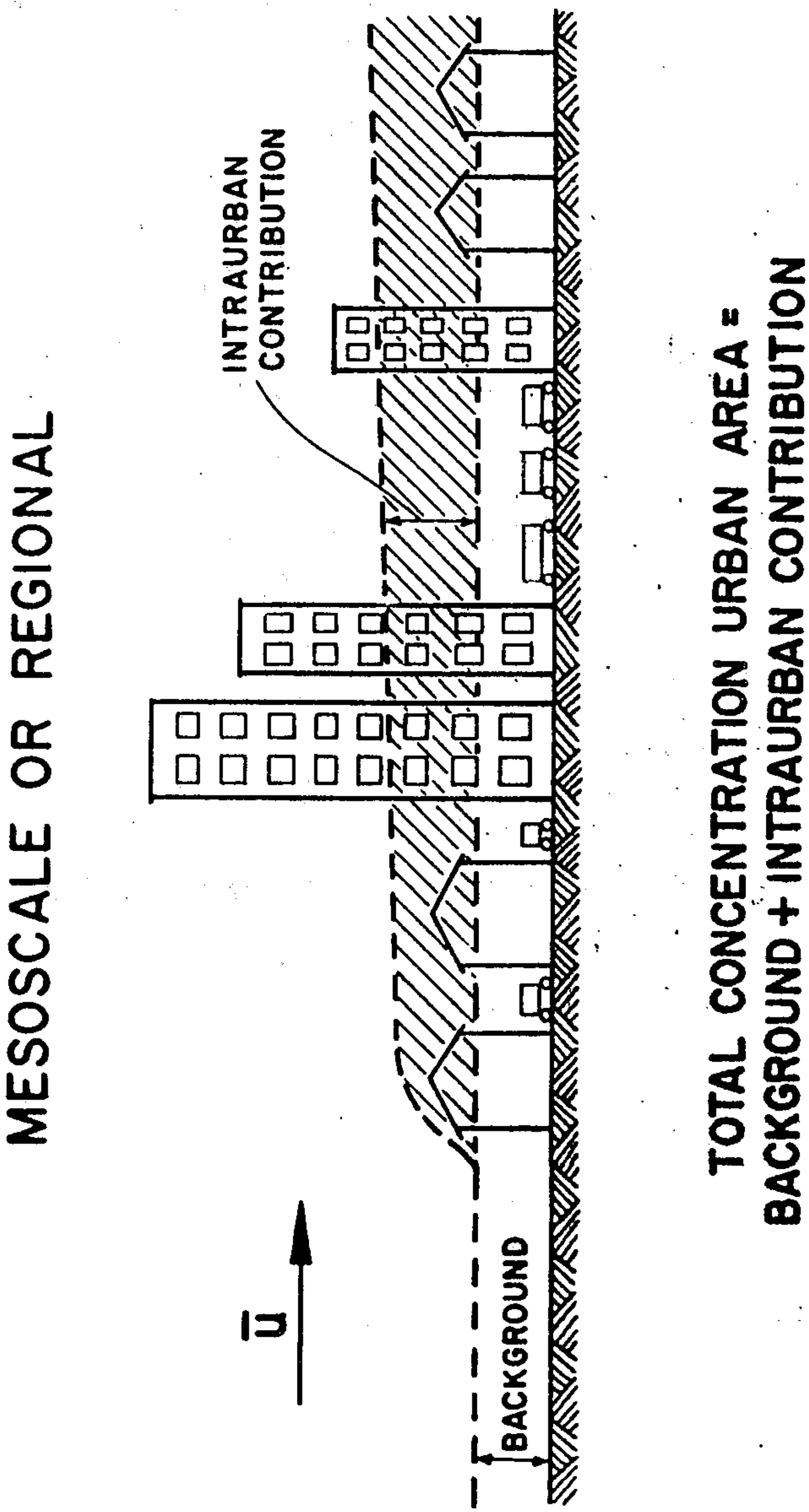
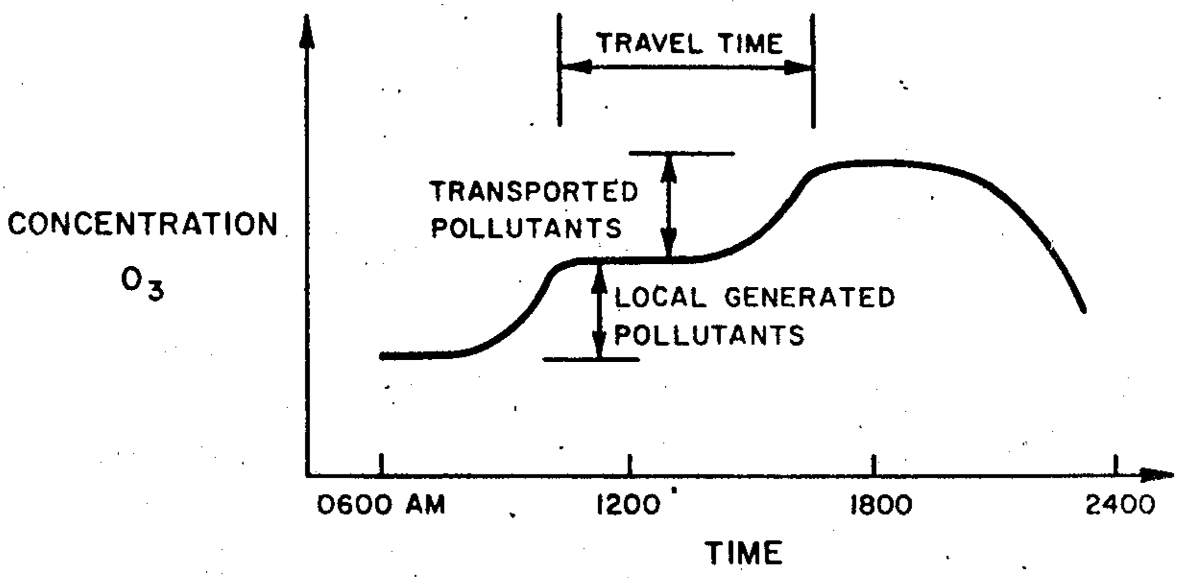
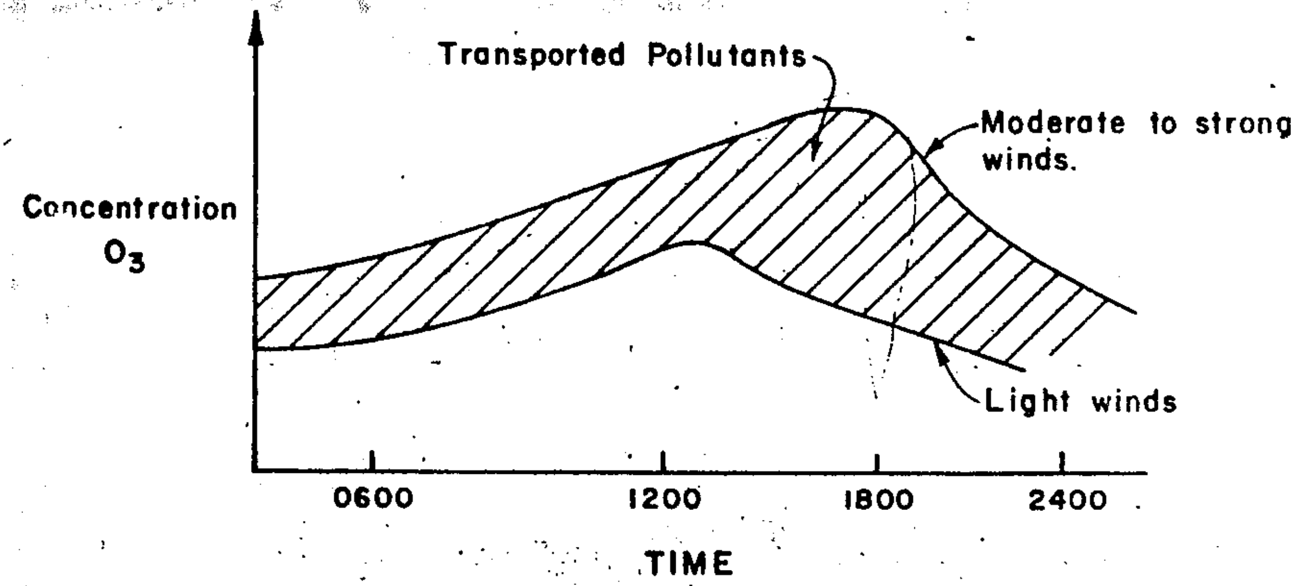

MESOSCALE OR REGIONAL
INTRAURBAN CONTRIBUTION
$\bar{U}$
BACKGROUND
TOTAL CONCENTRATION URBAN AREA =
BACKGROUND + INTRAURBAN CONTRIBUTION

FIGURE 7-2



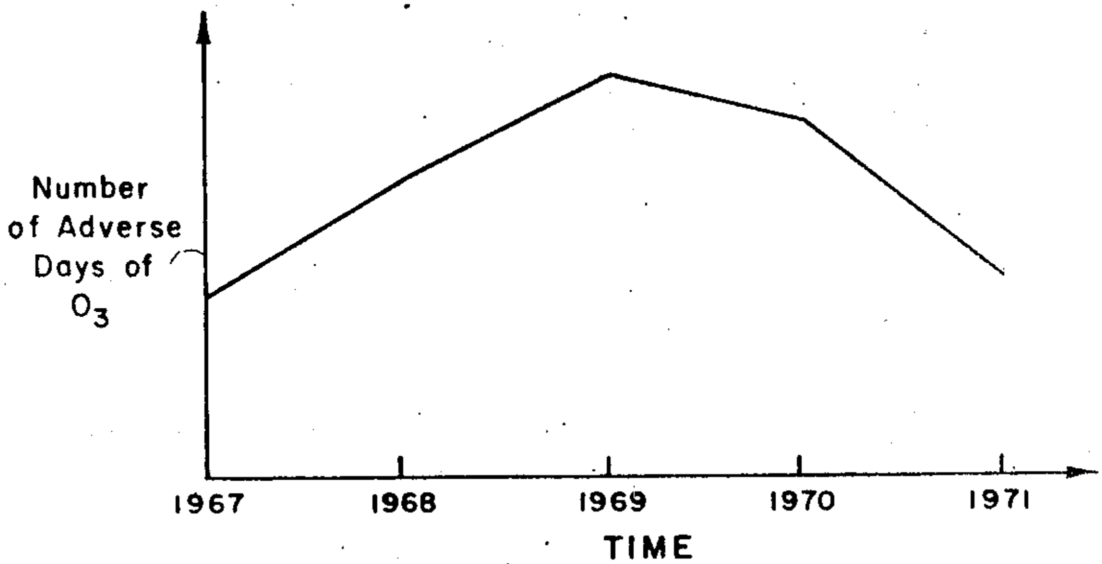
ESTIMATES OF TRANPORTED POLLUTANTS FROM OTHER AREAS BY DUAL PEAK ANALYSIS

FIGURE 7-3



ESTIMATES OF TRANSPORTED POLLUTANTS FROM OTHER AREAS BY SURFACE WIND ANALYSIS

FIGURE 7 - 4



NUMBER OF ADVERSE DAYS
AT AIR MONITORING STATION

F... 7-5

VI. Air Quality Data

A. Existing Sources

1. Local APCD
2. ARB
3. State and local public health agencies
4. Private consultant studies
5. Studies made by colleges, universities, etc.
6. Utility Companies
7. Industrial plants

B. Problems with Existing Data Sources for Transportation Studies

1. Additional pollutant sources between proposed highway and air monitoring station

2. Representativeness of air monitoring stations (Point measurement of regional air quality)

a. street canyon
b. Local traffic densities
c. probe location
d. upwind sources

3. Topography and terrain changes between proposed project and air monitoring station

4. Changes in meteorological conditions (wind speed and direction) between proposed project and APCD station

5. Natural Removal processes between project and APCD station

a. impaction

b. gravitational settling

c. absorption

d. chemical reactions

6. Distance from project and APCD station may allow photochemical reactions to take place

7. Historical changes in

   a. station location

   b. analytical methods - wet vs. dry chemical techniques

   c. adverse day criteria

8. Calibration and Maintenance Procedures

C. Analysis of Ambient Air Quality Data

   1. One hour averaging time

   2. Instantaneous peaks do not have ambient air quality standards

   3. Air and meteorological data must be analyzed for same time periods

      a. Characterize bad meteorological day

      b. Characterize bad air quality day

      c. Both must be consistent

D. Slides of APCD Stations

SECTION 8

AIR QUALITY SURVEYS

I. Levels of Air Quality Surveys

   A. Corridor Study - Project level analysis

   B. System Planning - Impact on entire community

   C. Construction Pollution

   D. Model Validation or Calibration

      1. Microscale
      2. Mesoscale

II. Air Quality Surveys With Fixed Stations and Mobile Van

   A. Use bag sampling techniques for CO

   B. Use Mobile Van primarily for secondary pollutants (O_3) in conjunction with fixed stations.

   C. Use statistical correlation techniques and regression analysis to predict the pollutant concentrations for days not monitored.

AIR QUALITY SURVEYS WITH FIXED STATIONS

I. Air Quality Trend Analysis -

See general flow chart Figure 8-1

A. Uses of Historical Meteorological Sources.

1. Statistical analysis of data will indicate the most probable and worst meteorological conditions to sample.

a. surface conditions
   (1) Stability classes A to F.

b. Upper air
   (1) Base of elevated inversions

NOTE: Do not design an air quality survey without a meteorological survey. Air pollutant data cannot be interpreted without knowledge of the meteorological conditions.

B. Use of historical data from APCD stations to determine trends.

1. Primary pollutants
2. Secondary pollutants

II. Design of Air Quality Surveys

A. State Objectives of Surveys

1. Microscale levels for proposed route
2. Microscale and regional levels

B. Locate All APCD Stations

1. Exposure

   a. Traffic
   b. Aerodynamic eddies

2. Representativeness of Project

   a. Topography
   b. Distance

C. Initial Correlation with APCD at Same Intake

1. To establish correlation between analyzers and sampling procedures.

   a. Beckman vs. MSA
   b. Wet chemistry vs dry chemistry
   c. Bag samples vs continuous monitoring

2. Credibility

3. Forces APCD to calibrate analyzers regularly

   a. APCD calibrated instrument 2-1/2 years ago.
   b. Calibrate when strip chart shows a gradual drift.

4. Correlate for three time periods

   a. Before any field measurements are made
   b. Midway through field study
   c. End of air quality survey

NOTE: All three are required to have a consistency check for the entire length of study.

5. Length of Correlation

   a. Consideration of variability of traffic and meteorology

      (1) A.M.
      (2) Midday
      (3) P.M.
      (4) Generally 8 hours (working day for APCD personnel)

   b. Cover the range of pollutant levels that you expect at APCD.

D. Select priority of projects to be monitored.

E. Determine number of sampling sites

   1. Homogeneous areas - see Page 17 of Ambient Air Manual

   2. Ideally located sampling site at all homogeneous areas.

   3. Consider influx and outfluxes of pollutants in study area.

F. Available manpower

   1. Manpower limits number of sites

      a. Select sensitive receptors - schools, hospitals, receptors 50-100 ft from highway

G. Sampling location

   1. Standardize height above ground surface - 5 feet or tower for high level receptors.

a. APCD Station - no standard height or exposure of air intake

2. Exposure of air monitoring station

   a. CO 200 to 400 feet from local freeways or surface arterial streets.

      (1) Ott Study in San Jose
      (2) Research Project in Los Angeles

3. Special Studies

   a. Replacing an existing highway

4. Temporal and spatial distribution of pollutants

   a. Use one hour averaging consistent with local practices of APCD. Sample all sites at same time.

H. Length of Field Study

1. Short-Term ($t \leq 6$ months) See Figure 8-2

   a. CO, HC, NO_2 - winter
   b. O_3 - summer, fall

2. Long-Term ($t > 6$ months)

   a. Season variation of pollutants

3. Daily sampling

   a. Traffic variability
   b. Urban 0600 to 1900

c. 24 hours - Special studies

d. Recreational traffic

e. Daily variation of pollutants

f. 24 hours routine bases.

4. Fixed or base stations and movable sites

I. Sampling Multiple Projects

1. Divide District into zones

a. Sample all projects in zone on a balanced randomized schedule to eliminate bias See Figures 8-3 and 8-4.

b. Randomly select sampling day per zone on a frequency of once per day.

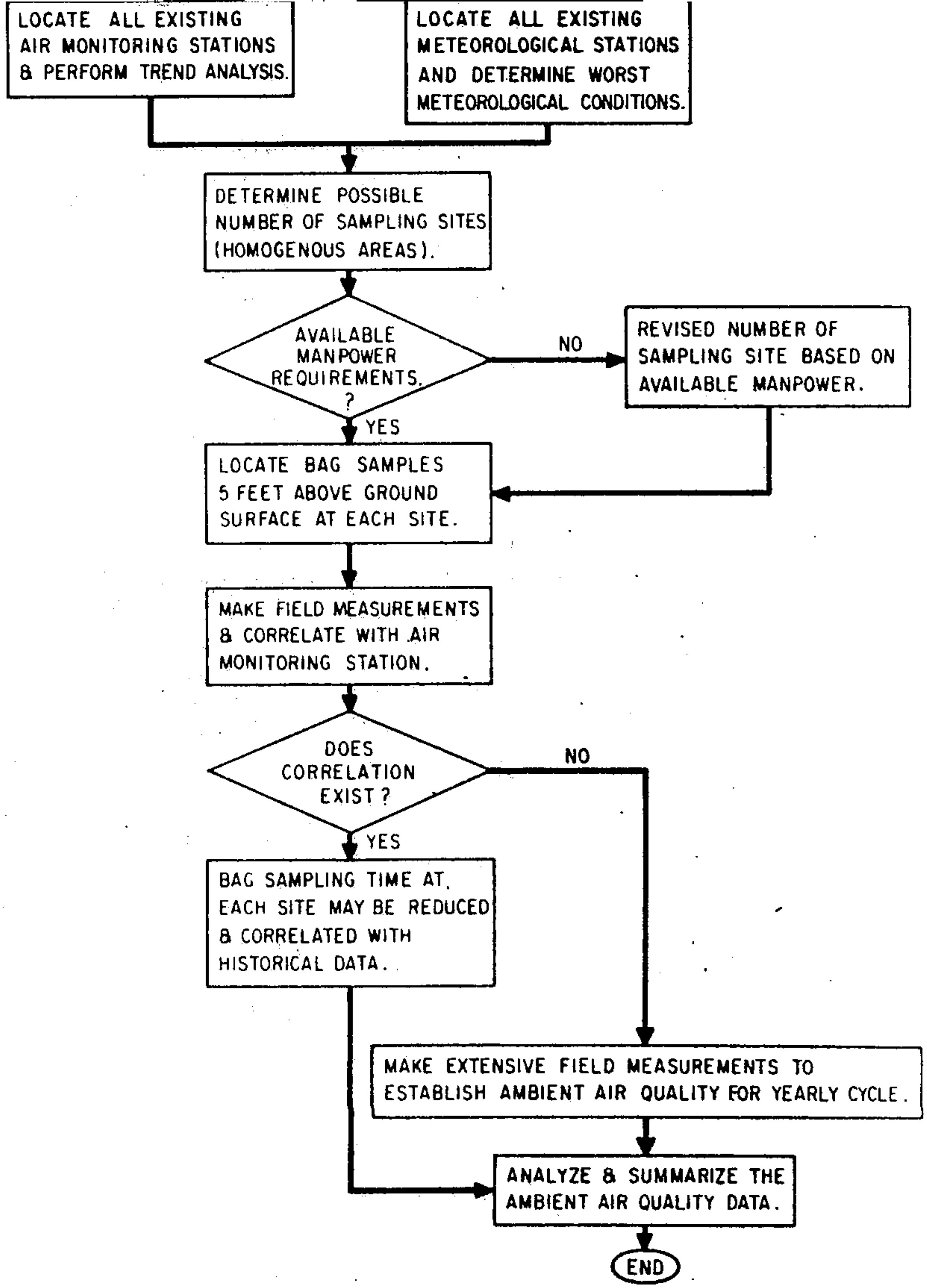
c. Special cases where logistics is a problem sample all projects within a zone every 3 to 4 days.

J. Correlation Analysis Using Regression Techniques

1. Reduce sampling time in field

a. Within a given season, summer, etc.

b. Predicted values must be within the range of the data used to obtain the regression equations.



FLOW CHART FOR AN AMBIENT AIR QUALITY SURVEY

FIGURE 8-1

LEVELS OF AMBIENT AIR QUALITY SURVEYS

SHORT TERM
($t \leq 6$ Months)

PURPOSE: To define the ambient levels for the winter season.

1 Random sampling of projects.

2 Sample every other day(s).

3 Statistical design based on daily analysis of data.

4 Generally sample as often as possible.

LONG TERM
($t > 6$ Months)

PURPOSE: To define the ambient levels for the winter & summer seasons.

1 Statistical design based on daily analysis of data.

2 Design based on non-parametric statistics & meteorological conditions.

3 Use of local U.S.W.B. Meteorologist for synoptic weather forecasts.

4 Sampling may not be required daily based on the analysis.

THE MAIN OBJECTIVE OF ANY AIR QUALITY SURVEY IS TO HAVE A WELL PLANNED PROGRAM OF MONITORING

FIGURE 8-2

BALANCED RANDOMIZED BLOCK DESIGN

	Projects or Sampling Locations						
Days or Week	1	2	3	4	5	..n	
1							BLOCK I
2							
3							
4							
5							
n							
1							BLOCK II etc.
2							
3							
4							
5							
n							

FIGURE 8-3

PROCEDURE FOR RANDOMIZED BLOCK DESIGN

1. SELECT PRIORITY PROJECTS.
2. SELECT (FOR EACH PROJECT) SAMPLING LOCATIONS BASED ON CRITERIA PRESENTED IN "AMBIENT AIR QUALITY MANUAL."
3. NUMBER EACH SITE CONSECUTIVELY STARTING WITH ONE.
4. USE RANDONIZED BLOCK DESIGN TO SELECT THE SAMPLING LOCATIONS TO MONITOR FOR A COMPLETE DAY USING EITHER OF THE FOLLOWING:

   (1) THROW OF DICE
   (2) RANDOM NUMBER TABLE
   (3) DRAW NUMBER FROM HAT

FIGURE 8-4

AIR QUALITY SURVEYS WITH MOBILE VANS

Purpose: Monitor for O_3 (Secondary Pollutant)

I. Select priorities of projects --

II. Determine diurnal surface wind streamlines

A. Historical meteorological data

B. Paper study

III. Analyze existing air quality data from APCD Stations

A. Determine the air quality trends

1. O_3 (secondary)
2. CO, HC, NO_x (primary)

IV. Determine areas of potentially high and low O_3 concentrations

V. Location of air monitoring site

A. Influx into project area

B. Mid-point

C. Outflux in project area

VI. Initial correlation with APCD Station

A. Credibility

B. Correlations of analyzers and procedures

1. Wet chemistry techniques
2. Dry chemistry techniques

C. Time periods to correlate

1. Before field measurements
2. Midway during field study
3. At end of field study
4. Consistency checks

D. Length of correlation

1. A.M.
2. Midday
3. P.M.

VII. Exposure

A. Locate station 200-400 feet away from local arterial streets to measure ambient levels of O_3

$$NO + O_3 \longrightarrow NO_2 + O_3$$

VIII. Length of Study

A. Air quality survey must be made in smog season - May through October.

B. Air quality survey for O_3 in winter is minor compared to primary pollutants such as CO, HC, NO_x.

IX. Daily Sampling

A. 0600 to 1900

1. Must cover daytime conditions

2. Special conditions may require nighttime sampling e.g., Palm Springs.

X. Sampling One Project

A. Monitor each site based on a balanced randomized design to eliminate bias.

XI. Sampling Multiple Projects

A. Monitor each site of all projects based on a balanced randomized design. Keep sampling sites to a minimum.

VII. Correlation Analysis Using Regression Techniques

A. Predict pollutant concentrations at air sampling sites on days when not monitored.

B. May possibly reduce sampling time for smog season.

NOTE: Do not design an air quality survey without a meteorological survey. Air pollutant data cannot be interpreted without knowledge of the meteorological conditions.

ANALYSIS OF AIR MONITORING DATA*

I. Correlation of Caltrans vs. APCD

A. See Figure 8-5

II. Temporal and Spatial Distribution of CO

A. See Figures 8-6 through 8-8

III. Summary Table for Ambient Air Quality

A. See Figure 8-9

*A detailed analysis of ambient air quality data is discussed in Reference 3 "Applications of Statistics in Analyzing Aerometer Data for Transportation Systems".

CORRELATION STUDY AIR QUALITY

PURPCSE: 1. To correlate different instruments and test procedures.

2. To correlate temporal & spatial distribution of CO based on APCD station.

STARTING TIME	CO CONCENTRATIONS (PPM)									
	STATE	APCD	SAMPLE SITE LOCATIONS							
			1	2	3	4	5	6	7	8
0800	11	9	3	8	8	3	3	3	3	4
0900	5	4	3	3	3	3	3	4	3	4
1000	5	4	3	–	3	3	3	3	3	4
1100	4	3	2	3	3	3	3	4	3	4
1200	4	3	2	3	3	3	3	4	3	4
1300	3	2	3	3	2	3	3	4	3	3
1400	3	2	2	2	3	3	8	3	3	4

METEOROLOGICAL MEASUREMENTS MUST BE MADE TO FULLY VALIDATE THE CORRELATION.

Figure 8-5

SUMMER AM CO READINGS (ppm)

TIME	APCD		SAMPLING SITES							
	A	B	1	2	3	4	5	6	7	8
0600-0700	10	6	5	5	8	7	5	8	7	8
0700-0800	14	7	4	7	8	6	8	9	8	9
0800-0900	5	4	3	4	7	4	5	7	6	5

WINTER AM CO READINGS (ppm)

TIME	APCD		SAMPLING SITES							
	A	B	1	2	3	4	5	6	7	8
0600-0700	21	13	8	14	22	9	15	8	8	13
0700-0800	21	15	12	14	24	14	18	14	9	17
0800-0900	18	24	22	14	28	11	27	19	12	17

FIGURE 8-6

SUMMER NOON CO READINGS (ppm)

TIME	APCD		SAMPLING SITES							
	A	B	1	2	3	4	5	6	7	8
1100-1200	5	7	3	3	3	5	6	8	8	5
1200-1300	7	3	3	3	3	4	5	5	5	4
1300-1400	5	4	3	3	3	3	3	3	5	5

WINTER NOON CO READINGS (ppm)

TIME	APCD		SAMPLING SITES							
	A	B	1	2	3	4	5	6	7	8
1100-1200	8	5	5	12	9	9	8	8	5	6
1200-1300	10	4	6	9	9	6	5	5	3	5
1300-1400	8	3	6	12	7	6	5	3	10	4

9 - 7

SUMMER PM CO READINGS (ppm)

TIME	APCD		SAMPLING SITES							
	A	B	1	2	3	4	5	6	7	8
1600-1700	6	3	3	3	3	3	4	3	3	3
1700-1800	8	3	2	3	3	4	4	4	4	4

WINTER PM CO READINGS (ppm)

TIME	APCD		SAMPLING SITES							
	A	B	1	2	3	4	5	6	7	8
1600-1700	15	4	3	3	6	5	3	3	7	5
1700-1800	15	8	3	3	6	4	6	4	6	6

SITES

HOUR	1	2	3	4	5	6
0600	A B C	A B C	A B C	A B C	A B C	A B C
0700	A B C	A B C	A B C	A B C	A B C	A B C
0800	A B C	A B C	A B C	A B C	A B C	A B C
0900	A B C	A B C	A B C	A B C	A B C	A B C

A = MINIMUM OR LOWER CONFIDENCE LIMITS (γ = .05)

B = MEDIAN (NOT AVERAGE).

C = MAXIMUM OR UPPER CONFIDENCE LIMITS (γ = .05)

AIR QUALITY INSTRUMENTATION SURVEY

LOCATION : BY : DATE :

1. A. MANUFACTURER :

   B. MODEL NO. : C. NAME :

2. A. PARAMETER B. PRECISION C. ACCURACY

3. MAINTENANCE SCHEDULE :

4. CALIBRATION SCHEDULE :

5. RECORDING INSTRUMENTS

   A. POWER SOURCE :

   B. AVERAGING TIMES :

   C. RECORDING METHOD :

   D. DATA HANDLING :

   E. PARAMETER/UNITS REPORTED

   F. CHART SPEED :

   G. SCALES :

   H. YEARS OF CONTINUOUS RECORD
      FOR INSTR. AT SAME LOCATION

6. EXPOSURE : A. OBSTRUCTIONS : B. TERRAIN :

   C. HEIGHT OF INTAKE :

7. PHOTOS : PANORAMICS AND 'CLOSE-UPS'

8. COMMENTARY : BY OF PHONE

GROUP PROBLEM DESIGN AIR QUALITY SURVEY

SECTION 9

AIR QUALITY INSTRUMENTATION

I. Air Quality Instrumentation

A. Proper Analyzer for Application

1. Carbon Monoxide - NDIR - Non Dispersive Infared. Figure 9-1
2. Ozone - Ultraviolet Light Absorption - UV Figure 9-2
3. Oxides of Nitrogen - Chemiluminescence with photometric detection Figure 9-3
4. Hydrocarbons - Gas Chromatography with flame ionization detection. Figures 9-4 through 9-6.
5. Hi-Vol Sampler

B. Representative Sample

1. Sample location
2. System inert
3. Reliable fittings and valves
4. Good Analyzer Support

a. "O" Air, Span Gases, H_2, etc.

C. CO Bag Samplers

D. Instrument Calibration

1. Outside Reference - Credibility
2. National Bureau of Standards
3. Test Procedures and Audit Survey

II. Meteorological

A. Mechanical Weather Stations

B. Directional vanes and cup anemometers

C. Bi-vanes - atmospheric turbulence

D. Relative humidity

E. Aircraft temperature package

F. Pibal - vertical wind profiles

G. Radiometer

III. Slides of Typical Equipment

NDIR DETECTOR

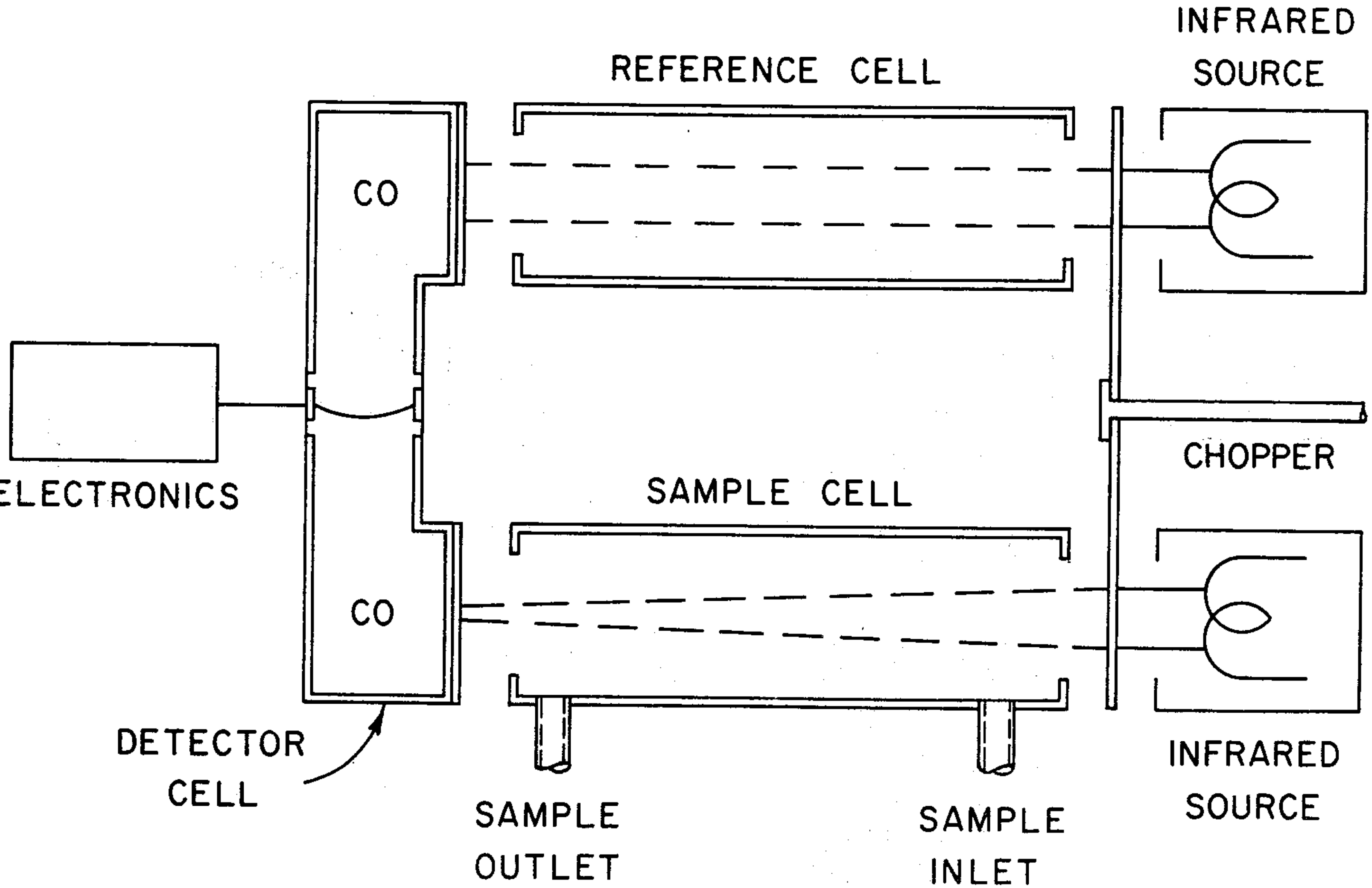


FIGURE 9-1

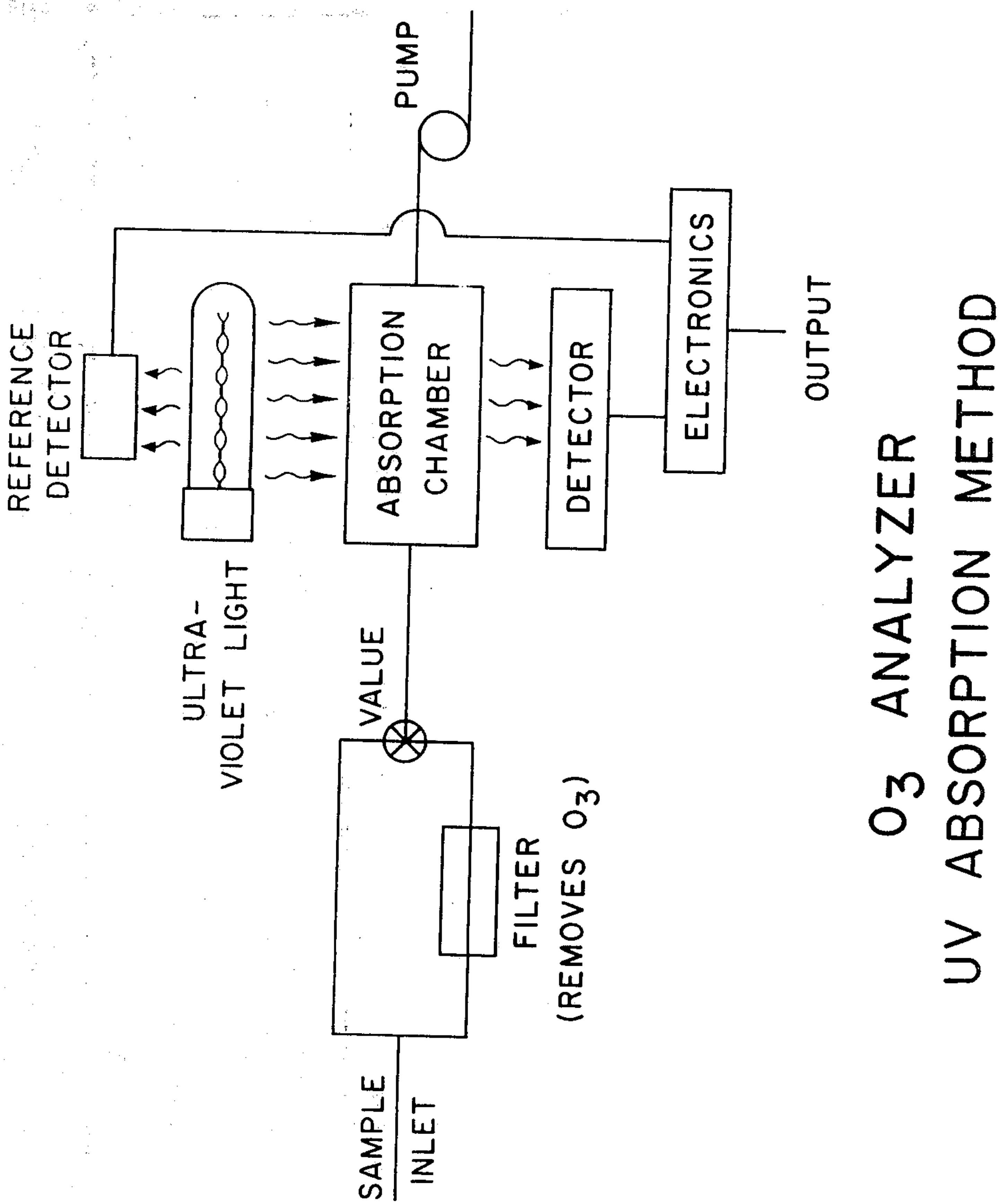
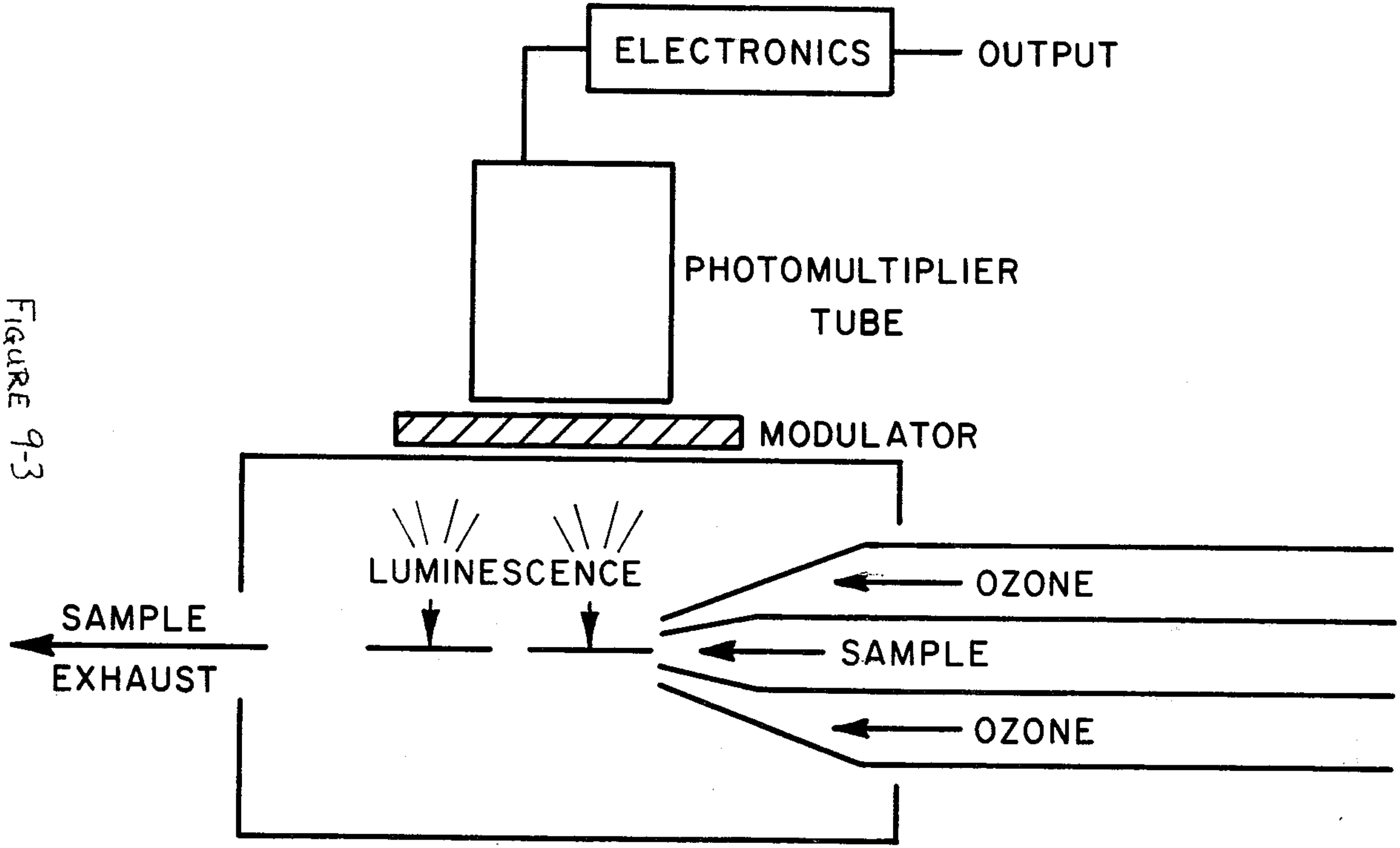
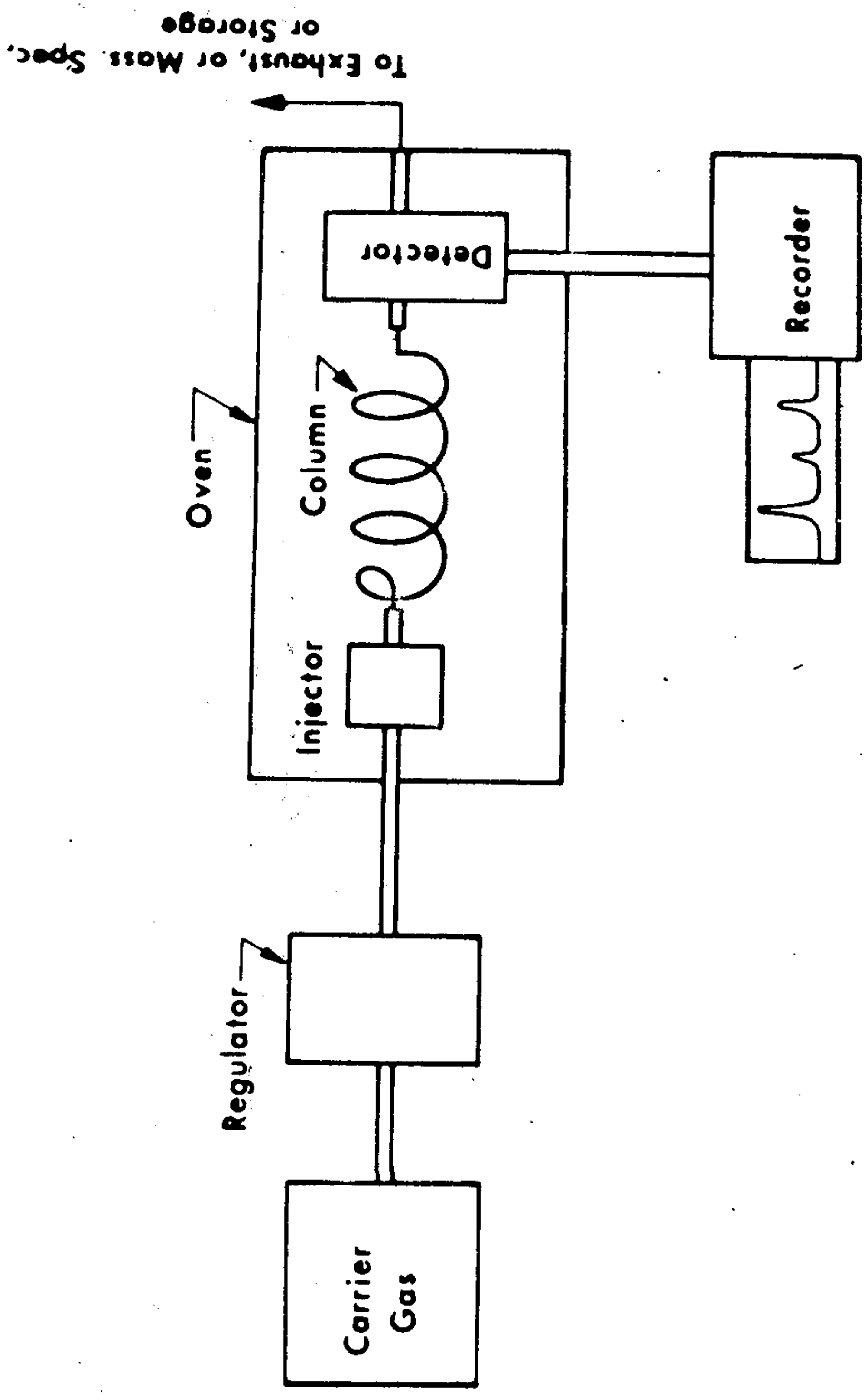

REFERENCE
DETECTOR
ULTRA-
VIOLET LIGHT
ABSORPTION
CHAMBER
DETECTOR
ELECTRONICS
OUTPUT
PUMP
VALUE
FILTER
(REMOVES O_3)
SAMPLE
INLET
O_3 ANALYZER
UV ABSORPTION METHOD

FIGURE 9-2



NO_x ANALYZER
CHEMILUMINESCENCE METHOD

FIGURE 9-3



Main components of the gas chromatograph.

FIGURE 9-4

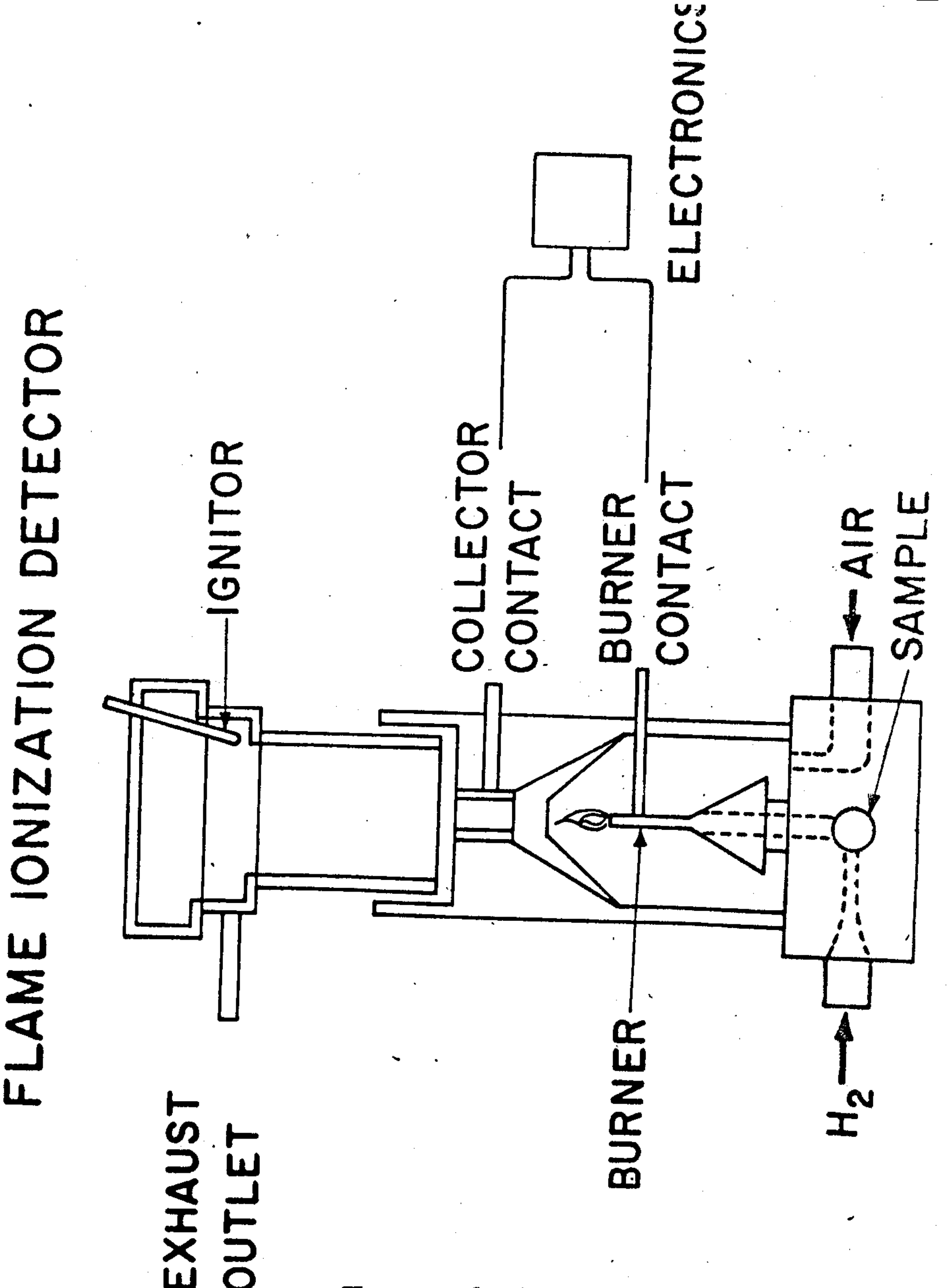
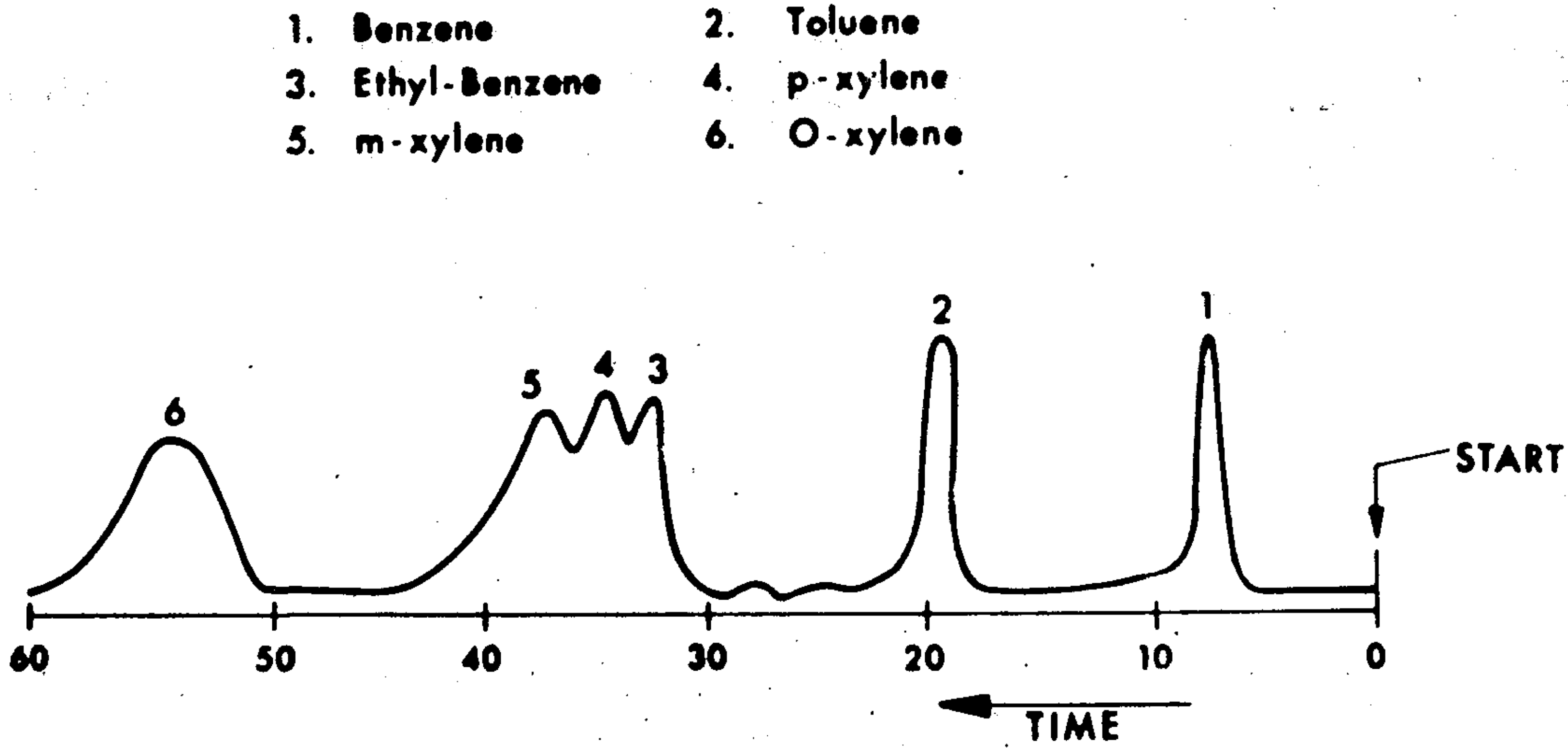

FLAME IONIZATION DETECTOR
EXHAUST OUTLET
IGNITOR
COLLECTOR CONTACT
BURNER CONTACT
ELECTRONICS
BURNER
AIR
SAMPLE
H_2

FIGURE 9-5



Typical gas chromatogram.

FIGURE 9-6

SECTION 10

AIR QUALITY MODELING

I. Purpose of Air Quality Modeling

A. Assess the impact of highways or multi-modal transportation systems on air quality.

B. Evaluate the impact of transportation control plans.

C. Provide a systematic procedure to evaluate the interrelationship of land use, transportation and air quality planning.

D. Provide information on where to locate air monitoring stations.

E. Select sites for future sources of air contaminants such as freeways, asphalt plants, etc.

F. Estimate air quality for areas in which pollutant measurements are unavailable.

G. Establish criteria for emission control legislation.

H. Provide a method to forecast areas where NAAQS and alert levels may be exceeded.

I. Comply with Federal and State legislation concerning environmental impact assessment.

J. Provide air quality predictions for compliance with indirect source regulations, where applicable.

MATHEMATICAL MODELING SCALES

Phenomena	Microscale	Mesoscale
Pollutant	Primary gaseous and particulate pollutants.	
		Products of photochemical reactions.
Space Scale	Mixing cell to ~ 200 m highway corridor	0.2 KM to 100 KM (City, air basin)
Time Scale	1 - 60 minutes	1 hour to 1 day
Primary Transport Process	Prevailing (geostrophic) wind.	
	Turbulence	Diurnal wind systems, sea & land.
Source of Transport Energy	Surface roughness, wind shear, connection	Horizontal temperature contrast, topography.
Primary Parameters	Wind speed, surface roughness.	
	Richardson Number	Latitude, stability (inversion ht.)
Typical Model	Line Source	Urban or regional.

FIGURE 10-1

II. Definition of Air Quality Model

A mathematical representation of the physical transport, mixing process, and chemical reactions that occur in the atmosphere after the release of a pollutant.

III. Mathematical Scales of Motion

A. Microscale

B. Mesoscale or Regional

C. See Figure 10-1

IV. Predictive Capabilities

A. Microscale - predict above baseline levels

B. Mesoscale or regional - predict above initial concentrations

C. See Figure 10-2 through 10-5

V. Modeling Characteristics

Air Quality Models should include:

A. High Spatial Resolution

1. Microscale

a. Lane width
b. Roadway width
c. Geometry of highway section
d. choice of receptor location
e. Choice of wind direction

2. Mesoscale

a. Choice of receptor location

B. Time Resolution

1. Microscale and Mesoscale

a. Changes in traffic densities.
b. Changes in meteorology

(1) $\bar{U}$ and ϕ
(2) Stability - surface and elevated

C. Consider Local Mixing Effects

1. Microscale

a. Mixing cell
b. Aerodynamic effects of fills
c. Aerodynamic effects of cuts
d. Aerodynamic effects of viaducts
e. Surface roughness characteristics

2. Mesoscale

a. Surface roughness characteristics.
b. Mixing process below elevated inversion

D. Capability of Arbitrary Wind Direction

1. Mesoscale and Microscale

a. Normal
b. Oblique
c. Parallel

E. Inclusion of Chemical Reactions

1. Microscale

a. $NO+O_3 \rightarrow NO_2+O_3$

2. Mesoscale

a. Photochemical Reactions

F. Computational Efficiency

1. Microscale and Mesoscale

a. Computer time
b. Logistics of input data

G. Models should be rational in the development of the physical and mathematical equations.

VI. Level of Analysis for Air Quality Modeling

A. Microscale

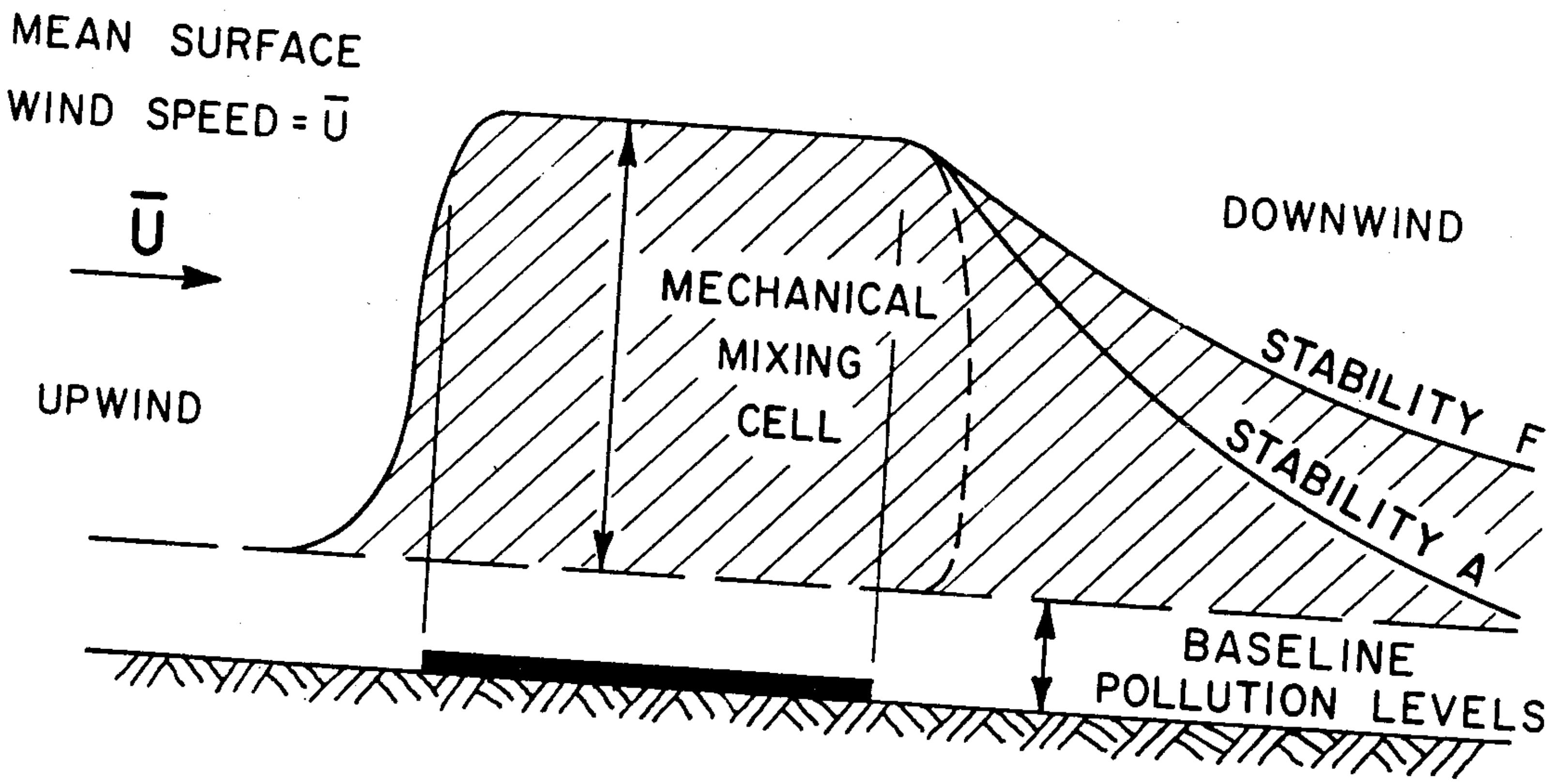
1. Box or Empirical - mixing cell
2. Gaussian - Downwind transport and diffusion
3. Conservation of Mass - Mixing cells, downwind transport and diffusion

B. Mesoscale or Regional

1. Pollutant Burden - Rollback (CO, NO_2, O_3)
2. SRI APRAC-1A - Gaussian Model for CO only
3. Conservation of Mass - Photochemical models

C. Real World - Combinations of empirical and physical analyses

WINDS NOT PARALLEL TO HIGHWAY ALIGNMENT



MODEL ESTIMATES ONLY SHADED AREA.

TOTAL POLLUTANT CONCENTRATION = BASELINE POLLUTANT LEVELS + POLLUTANTS GENERATED FROM HWYS.

FIGURE 10-2

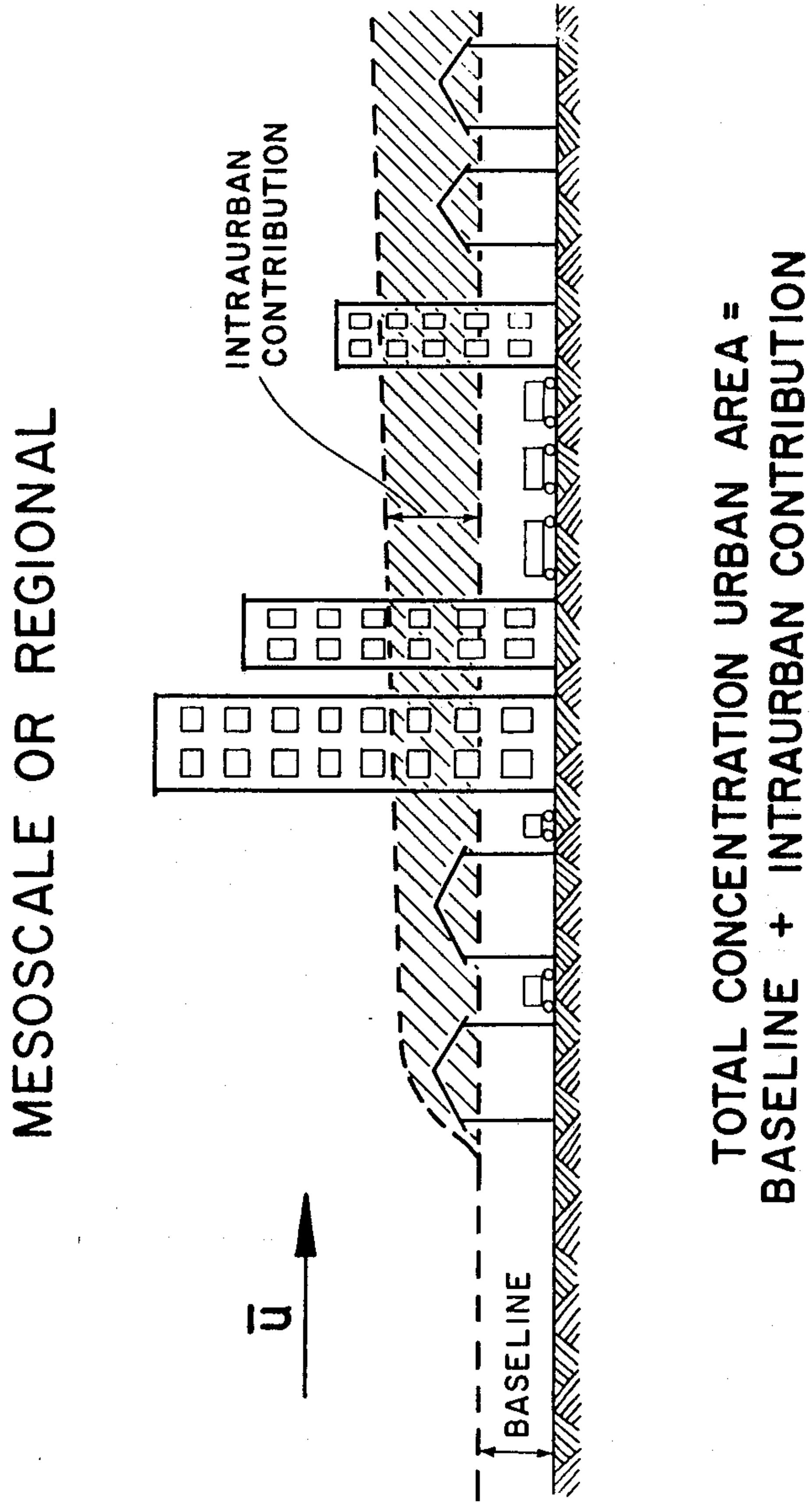

MESOSCALE OR REGIONAL
INTRAURBAN CONTRIBUTION
$\bar{U}$
BASELINE
TOTAL CONCENTRATION URBAN AREA =
BASELINE + INTRAURBAN CONTRIBUTION

FIGURE 10-3

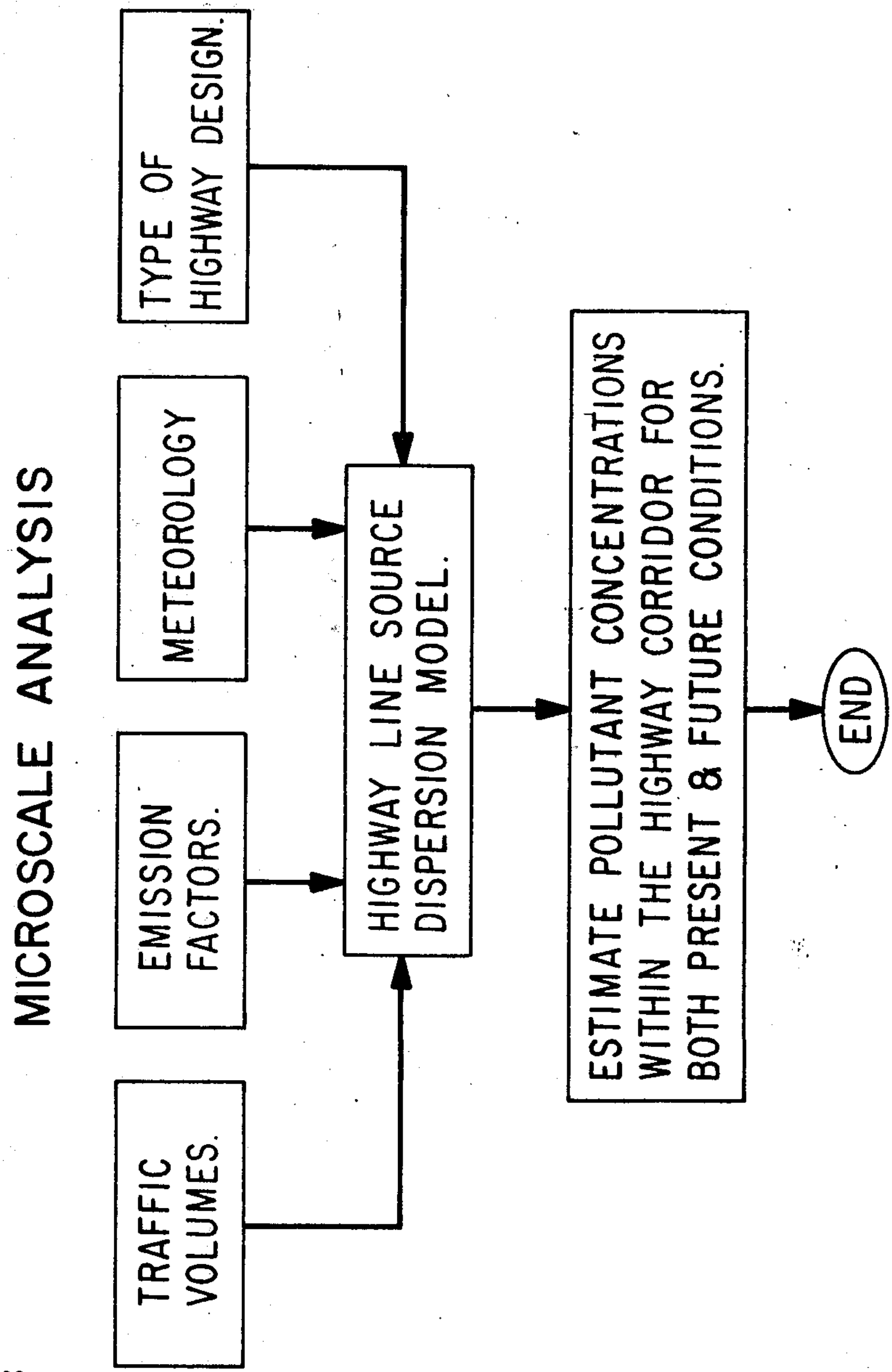

MICROSCALE ANALYSIS
TRAFFIC VOLUMES.
EMISSION FACTORS.
METEOROLOGY
TYPE OF HIGHWAY DESIGN.
HIGHWAY LINE SOURCE DISPERSION MODEL.
ESTIMATE POLLUTANT CONCENTRATIONS WITHIN THE HIGHWAY CORRIDOR FOR BOTH PRESENT & FUTURE CONDITIONS.
END

FIGURE 10-4

REGIONAL ANALYSIS

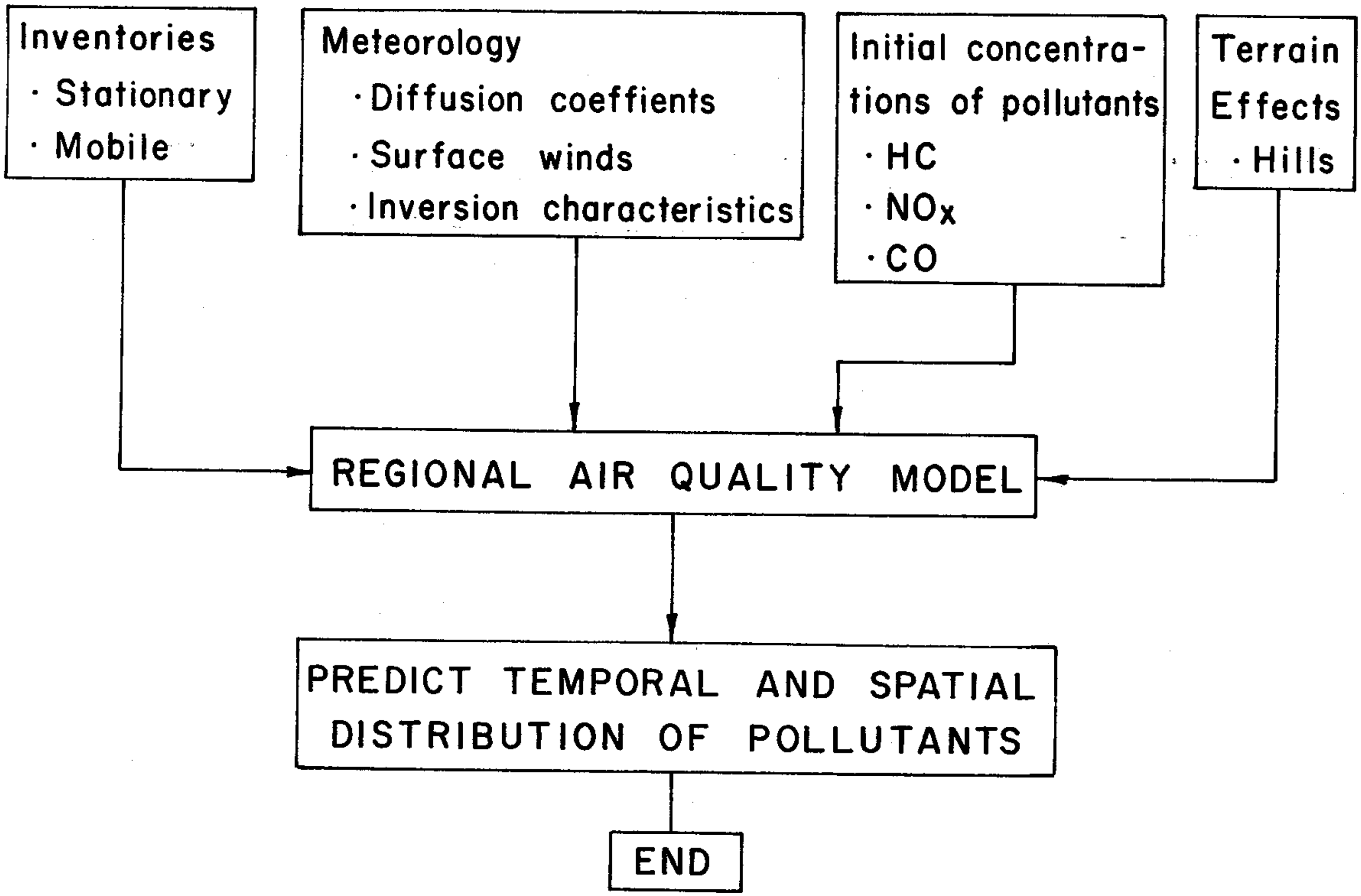


FIGURE 10-5

VII. Types of Air Quality Models

A. Box Models

Assumptions

1. Pollutant concentrations are homogeneous through the region of interest.

2. The source is distributed uniformly.

3. The emitted pollutants are instantaneously and uniformly mixed.

4. A uniform wind characterizes the transport.

5. A constant height through which mixing is vigorous is typical of time averaged meteorology.

$$C = \frac{nEl}{wh\bar{u}}$$

where C = concentration in mass per unit volume

n = vehicles per hour

E = emission factor in gram per unit length as a function of route speed

l = length of box section

w = width of box section

h = height of box section

$\bar{u}$ = wind speed

B. Gaussian Plume Model

This model was originally developed to describe the concentration distribution of an inert pollutant downwind from a point source (industrial stack).

It has subsequently been extended for applications to line and area sources by imposing the principle super-position. In the usual applications of this model the assumptions are:

1. Only inert pollutants are considered.

2. Wind shear is neglected.

3. Measures of plume spread are assumed constant and are based on experimental studies, usually carried out over rural areas. They are a function of atmospheric stability class.

4. Pollutants are distributed normally in both the crosswind and vertical directions

5. Conservation of mass - no loss of pollutants.

General Equation: See Figures 10-6 and 10-7

Application of Gaussian Models: Flat open areas free of terrain effects that may alter the surface winds.

C. Equation of Conservation of Mass

This approach can include:

1. Temporal variations in meteorological conditions.

2. All types of highway designs, depressed sections, interchanges.

3. Irregularities in terrain features.

4. The effects of land use in construction of the wind flow field and in the turbulent diffusivities.

5. Wind patterns of any type.

6. Variations in atmospheric stability. These are treated through the choice of vertical turbulent diffusivity.

<u>General Equation:</u> See Figure 10-8

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x}\left[K_x\frac{\partial c}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y\frac{\partial c}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_z\frac{\partial c}{\partial z}\right] + R_i + S_i$$

where c_i = time-averaged concentration of species i

u, v, w = time-averaged wind components in the x, y, and z direction respectively

K_x, K_y, K_z = turbulent eddy diffusivities

S_i = volumetric rate of emission of species i

R_i = chemical reactions

<u>Limitations:</u>

The computational requirements for the solution of these equations can be substantial, both with respect to <u>computing time</u> and <u>computer storage</u>.

The following should be considered when using this approach:

1. Will it predict ground level concentrations with acceptable accuracy compared with more simplified approaches?

2. Assuming that the model is of acceptable accuracy, can it be operated at a reasonable cost, given the computing time and computer storage requirements associated with such an effort?

D. Statistical Multiple Regression Analysis

This approach is based on the statistical analysis of observed data. It includes the following:

1. Establishes and evaluates the distribution of pollutants near a source.

2. Isolates and assesses the significance of parameters influencing the concentrations, transport and diffusion of pollutants.

3. Evaluates the observed dependencies based on known physical and newly postulated principles.

4. Parameterizes the dependencies.

Limitations:

Generally these regression models are applicable for limited types of highway designs and meteorological conditions, or given regional areas.

E. Combinations of above approaches

1. Empirical and physical concepts are included.

VIII. Applications of Microscale and Regional Air Quality Models

A. Transportation Alternatives

1. No build
2. Spatial
3. Modal
4. Temporal
5. Design

B. Forecast Years

1. Present or Baseline year
2. ETC
3. ETC+10 years
4. ETC+20 years

C. Meteorology - Typical and Bad Day

1. Summer - O_3
2. Winter - CO, HC, NO_x

GENERAL GAUSSIAN EQUATION

$$\frac{C(X,Y,Z)\,\bar{U}}{Q} = \frac{1}{2\pi\sigma_Y\sigma_Z}\left[\mathrm{EXP}-\frac{1}{2}\left(\frac{Y}{\sigma_Y}\right)^2\right]\left[\mathrm{EXP}-\frac{1}{2}\left(\frac{Z+H}{\sigma_Z}\right)^2+\mathrm{EXP}-\frac{1}{2}\left(\frac{Z-H}{\sigma_Z}\right)^2\right]$$

C = CONCENTRATION

$\bar{U}$ = WIND SPEED

σ_Y, σ_Z = TURBULENCE PARAMETERS

Z = RECEPTOR HEIGHT

H = EFFECTIVE STACK HEIGHT

Y = RECEPTOR LOCATION FROM ℄ OF PLUME

FIGURE 10-6

SIMPLIFIED GAUSSIAN EQUATION TERMS

$$\text{CONCENTRATION} = \frac{(\text{SOURCE STRENGTH})}{(\text{TRANSPORT WIND})(\text{TURBULENCE})} \boxed{\text{RECEPTOR \& SOURCE HEIGHT}}$$

SOURCE STRENGTH = f(VPH, EF)

TRANSPORT WIND = $\bar{U}$ = HORIZONTAL WIND

TURBULENCE = σ_Y, σ_Z = f(STABILITY, DISTANCE)

RECEPTOR LOCATION = Z,Y

SOURCE HEIGHT = H

FIGURE 10-7

DECOM

$$\underbrace{\frac{\delta c}{\delta t}}_{\text{RATE OF CHANGE OF CONCENTRATION}} + \underbrace{u\frac{\delta c}{\delta x} + v\frac{\delta c}{\delta y} + W\frac{\delta c}{\delta z}}_{\text{WIND FLOW FIELD ADVECTION TERM}} = \underbrace{\frac{\delta}{\delta x}\left[K_x\frac{\delta c}{\delta x}\right] + \frac{\delta}{\delta y}\left[K_y\frac{\delta c}{\delta y}\right] + \frac{\delta}{\delta z}\left[K_z\frac{\delta c}{\delta z}\right]}_{\text{DIFFUSION TERM}} + \underbrace{Si}_{\text{SOURCE}} + \underbrace{Ri}_{\text{CHEMICAL REACTION}}$$

u, v, & W = x, y, & z WIND SPEEDS

K_x, K_y, & K_z = DIFFUSIVITY COEFFICIENTS

BOUNDARY CONDITION:

$$\left.\begin{array}{l} \frac{\delta c}{\delta t} = 0 \\ v = W = 0 \end{array}\right\} \text{GAUSSION SOLUTION (STEADY STATE)}$$

FIGURE 10-8

SECTION 11

SENSITIVITY ANALYSIS OF EXISTING AIR QUALITY MODELS

I. Definition: Sensitivity analysis can be defined as the fractional variation of the predictive concentration as a function of the fractional changes in the model input parameters. The goal is to assess the influence of each parameter insofar as predicted air quality is concerned.

II. Evaluation and Model Development

A. More effective evaluation if sensitivity analysis is made in terms of:

1. input data requirements
2. accuracy of inputs
3. cost effectiveness

III. Important Considerations for Transportation Planners and Engineers Using Existing Air Quality Models

A. Accuracy of air quality estimates are strong function of the quality of input data

B. Inevitable uncertainties and inaccuracies in information available.

1. Traffic
2. Emission factors
3. $\overline{u}$, ϕ
4. Stability
5. Inversion heights
6. Solar radiation intensity

C. Air quality calculations are subject to a range of uncertainty which should be specified if possible.

D. Example: Instrumental accuracy and site characteristics suggest an uncertainty of $\pm$ 2 mph, what uncertainty will this introduce into the output calculation of air pollution concentrations?

IV. Important to know the effects in output values caused by changes in inputs.

A. Small change in input $\rightarrow$ large change in output.

1. Model is sensitive to that input

2. Must provide accurate value of input to avoid large errors in outputs.

B. Large changes in inputs $\rightarrow$ little effect on outputs.

1. Don't need high input accuracy to achieve high output accuracy for that particular variable.

V. Combination of Parameter Values

A. Model outputs could be possible totally independent to the changes in one or more inputs.

VI. Sensitivity Analysis for Microscale Models

A. Input parameters to consider:

1. What are the effects of traffic volume inputs on the predictions?

2. What are the effects of emission factors inputs on the predictions?

3. What are the effects of wind speed inputs on the predictions?

4. What are the effects of wind direction inputs on the predictions?

5. What are the effects of atmospheric stability input on the predictions?

6. What are the effects of highway design input on predictions?

7. What are the effects of receptor location input on predictions?

8. What are the effects of numerical stability input on predictions?

9. Combination of above parameters

VII. Sensitivity Analysis of Regional Models

A. Input parameters to consider:

1. What effects do the time distribution of traffic volumes have on the predicted concentrations?

2. What effects do the area source or grid size have on predicted concentrations?

3. What effect does the inversion height have on predicted concentrations?

4. What effects do the wind shear or mean surface winds have on the predicted concentrations? What about exposure of sensors for existing wind data?

5. What effects do the surface roughness heights have on predicted concentrations?

6. What effects do the diffusivity coefficients have on the predicted concentrations?

7. What effect does the UV radiation intensity have on predicted concentrations (clear day compared to hazy day).

8. What effect do the emission factors for CO, HC, NO_x have on predicted concentrations?

9. What effect does the number of wind stations have in determining wind trajectories?

10. What are the effects of the reaction rates for the formation of photochemical smog?

11. What are the effects of numerical stability on the predicted concentrations?

VIII. Proper Sensitivity Analysis Can Determine:

A. Data requirements
B. Accuracy of input required
C. Cost effectiveness of collecting inputs
D. Applications

IX. Sensivity Analysis does not:

A. Indicate that the theoretical approach used is valid.
B. Indicate whether or not a model is verified with field data.

SECTION 12

CALIFORNIA LINE SOURCE DIFFUSION MODEL (CALINE2)

I. Model Characteristics

A. Relates

1. Traffic volumes
2. Emission Factors
3. Meteorology
4. Type of Highway Design

B. Predict concentrations for gaseous pollutants

1. CO - inert, stable gas O.K.
2. HC - provide a health standard and separate the reactive hydrocarbons.
3. NO_2 - no predictions because of the reaction

   a. $NO + O_3 \rightarrow NO_2 + O_2$
   b. % of NO_x is NO_2

4. Does not consider particulates
5. Predicts above baseline levels - See Figure 12-1

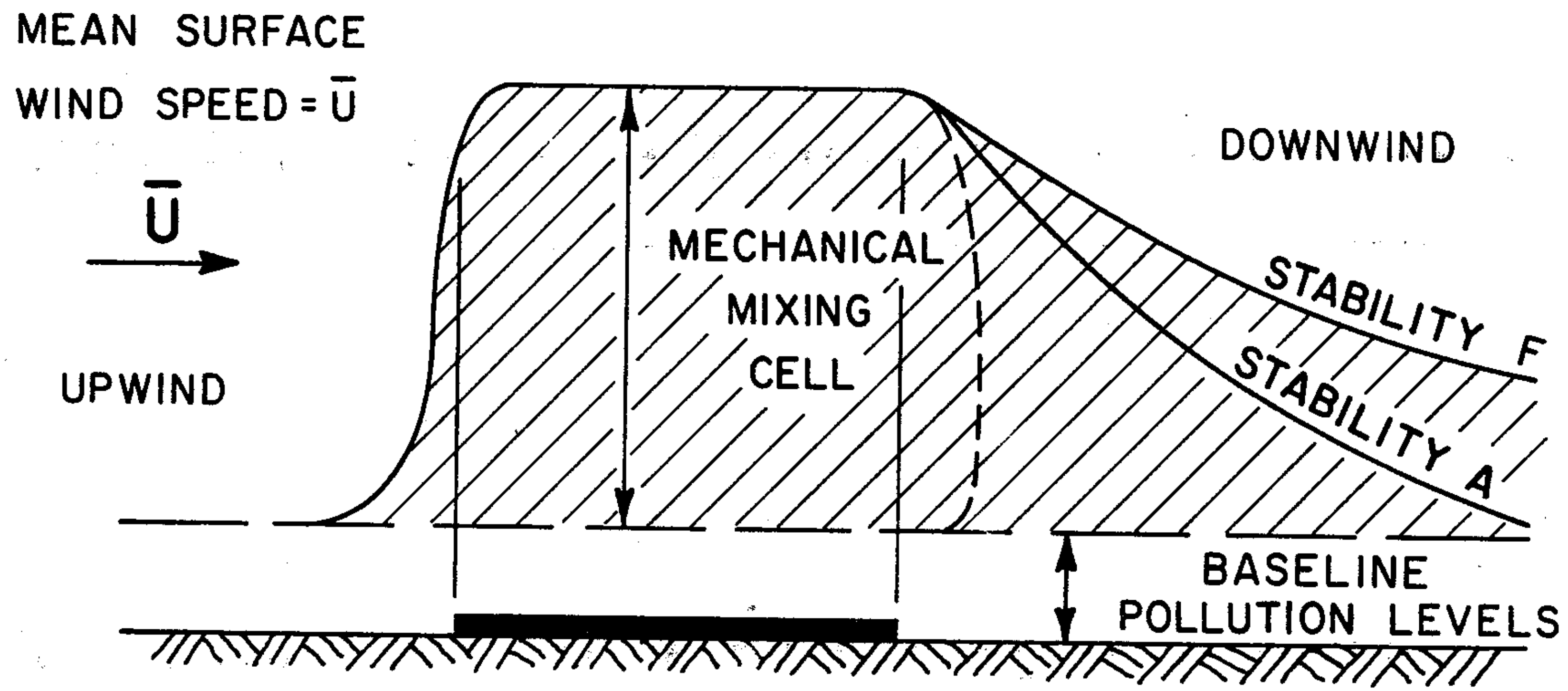
II. Modeling Approach

A. Box - mechanical mixing cell

B. Gaussian - downwind transport and diffusion

C. See Figure 12-2

WINDS NOT PARALLEL TO HIGHWAY ALIGNMENT



MODEL ESTIMATES ONLY SHADED AREA.

TOTAL POLLUTANT CONCENTRATION = BASELINE POLLUTANT LEVELS + POLLUTANTS GENERATED FROM HWYS.

CALINE LINE SOURCE MODEL

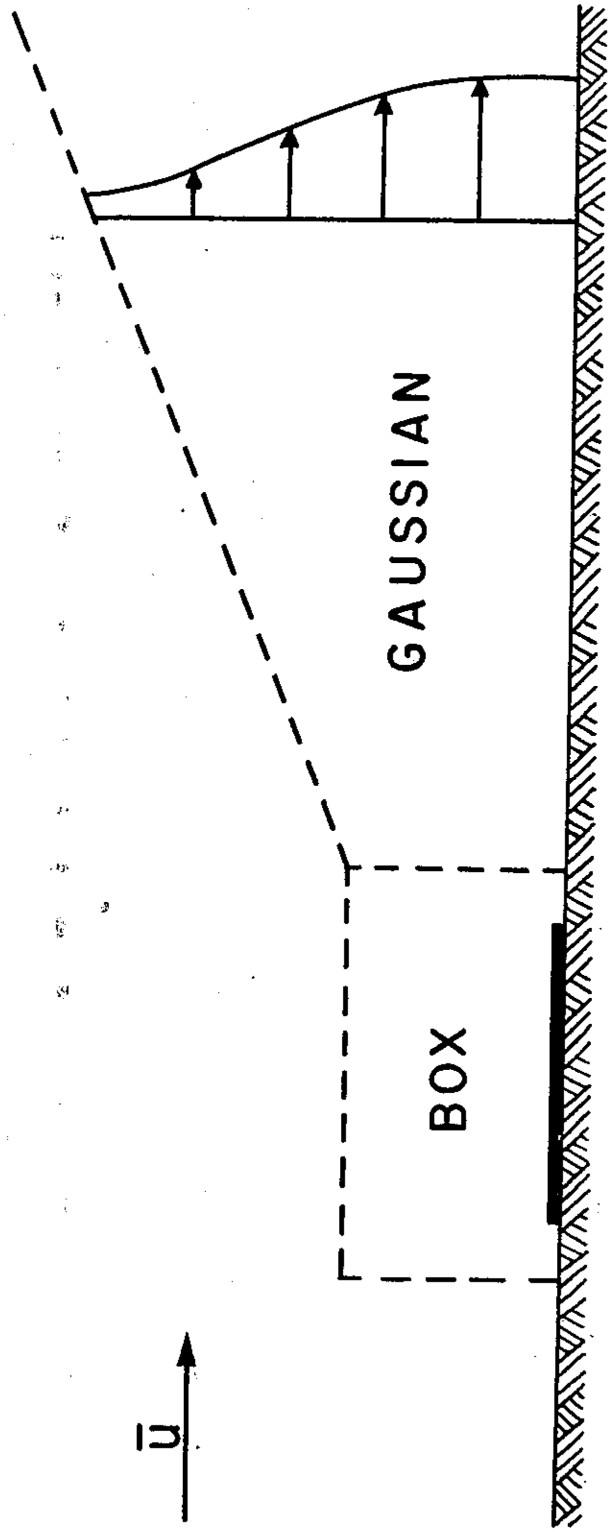


FIGURE 12-2

III. CALINE2 Model

A. Assumptions

1. Normal distribution of pollutants in the horizontal and vertical directions.

2. Continuous emission source from vehicles on highway for time period analyzed.

3. Stability of the atmosphere is based on studies made by Pasquill and Turner.

4. The concentration within the mechanical mixing cell is independent of stability class. (The mechanical mixing cell is defined as the initial dispersion of pollutants caused by the motion (turbulence) of the moving vehicles.)

5. The vertical height of the mechanical mixing cell is assumed to be 4 meters. The horizontal width of the cell is assumed to extend from edge of pavement to edge of pavement for medians less than or equal to 30 feet.

6. A uniform wind field exists.

7. No aerodynamic effects on air passing over structures, etc.

B. Difficulties of Gaussian Models

1. Original development of turbulent parameters σ_y and σ_z

   a. Flat open area in Kansas and gently rolling hills in England, representative for flat open areas only.

   b. σ_y and σ_z

      (1) σ_y and σ_z a function of horizontal distance from source

      (2) Original σ_y and σ_z valid only for 0.1 kilometer (328 feet) horizontal distance from source and greater

   c. Project smoke - smoke candles

      (1) Purpose:

         (a) Determine general dispersion characteristics from line source

         (b) Examine the mechanical mixing cell

         (c) Obtain rough estimate of σ's near source

      (2) Project conducted on airport runway under neutral atmospheric stability and with surrounding terrain flat and open.

      (3) 4 meters found as upper limit of mechanical mixing cell

2. Modification of σz to incorporate results from project smoke

   a. See Figure 12-3

3. Wind Speed - height to measure $\overline{U}$ because of the wind shear and ground turbulence

   a. See Figure 12-4 - exposure for air flow around building

   b. Standard h = 10 meters or equivalent. Also method to estimate surface stability uses $\overline{U}$ at 10 m.

C. Model Inputs

1. Traffic volumes - vehicles/hour (VPH)

2. Emission Factors - Function of route speed and percent heavy duty vehicles

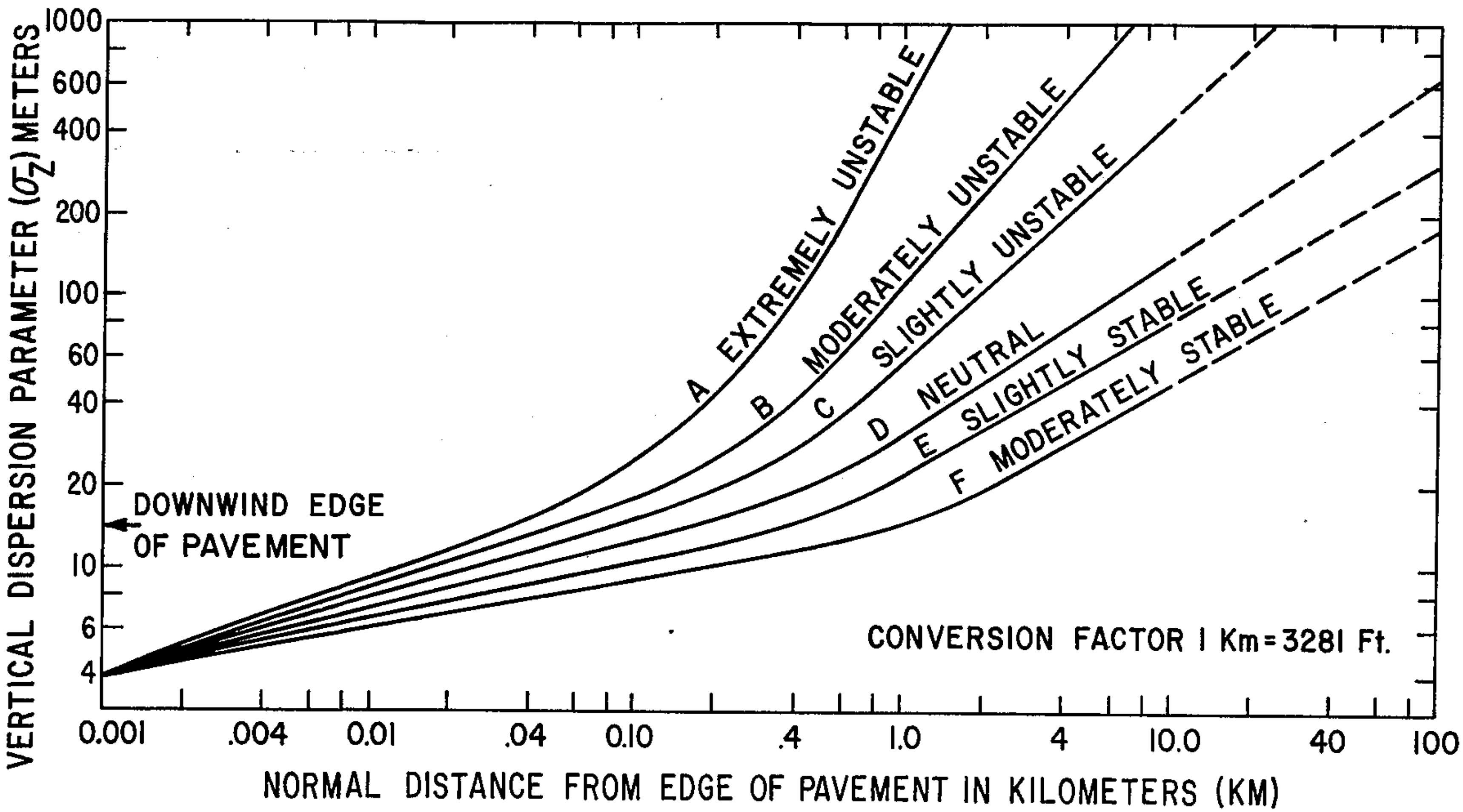
3. Meteorology

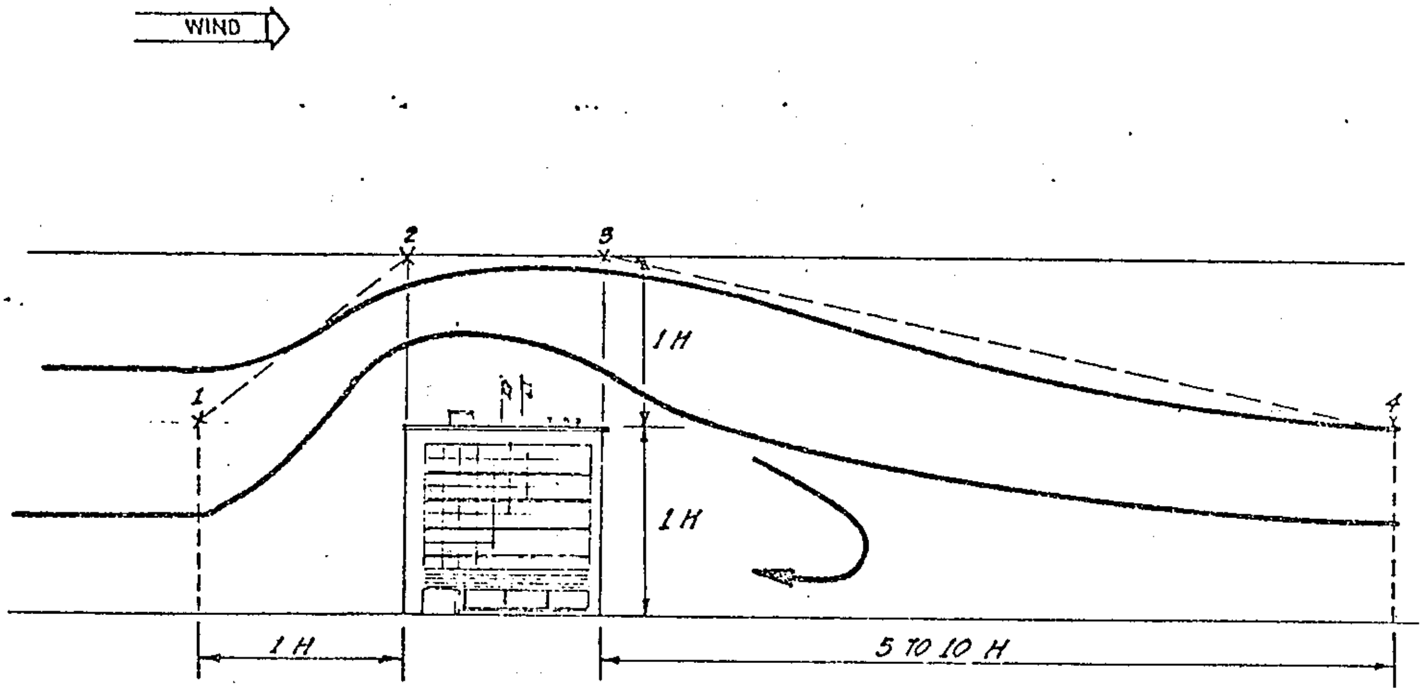
   a. Atmospheric stability class
   b. Wind speed
   c. Wind angle to highway alignment

4. Type of Highway Design

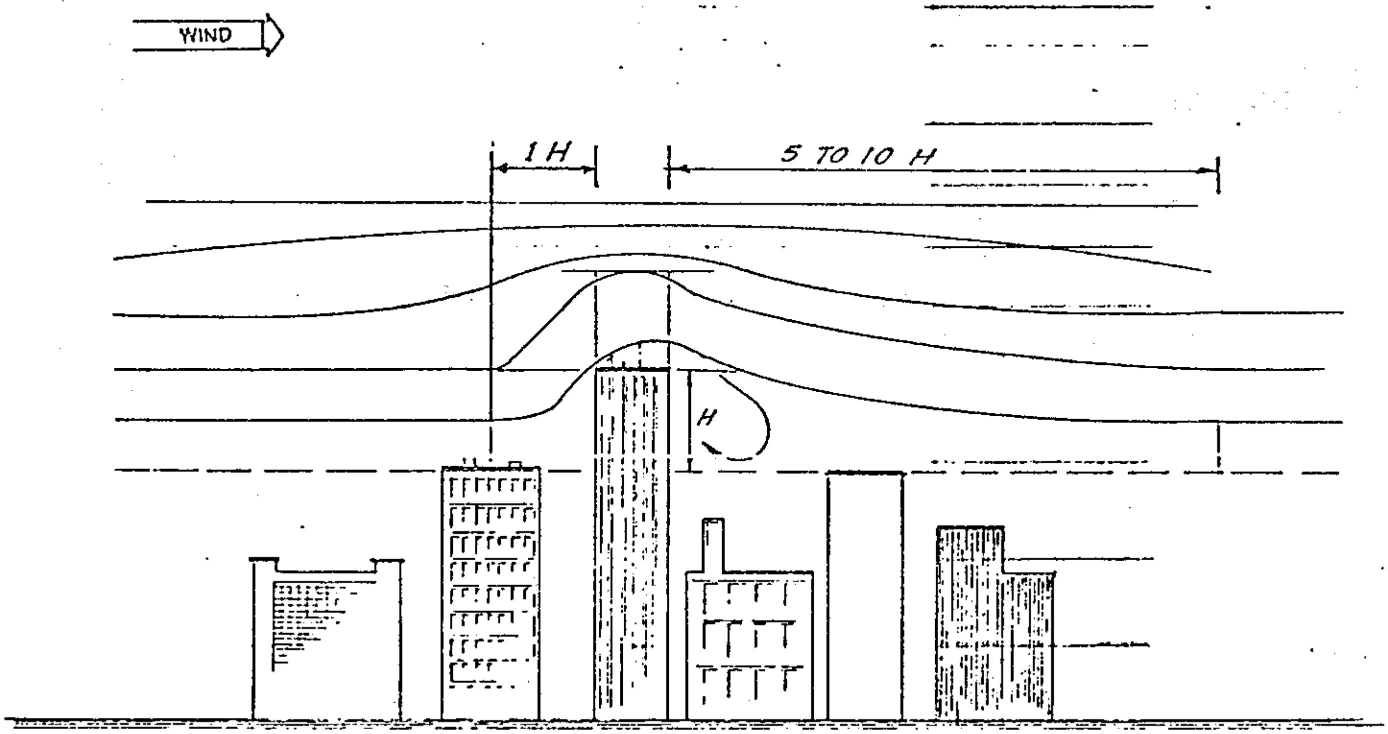
   a. Pavement height above or below grade
   b. Width of roadway, including all lanes, median and shoulders

VERTICAL DISPERSION PARAMETERS





PROPER EXPOSURE OF WIND SYSTEMS
NEAR CUBICAL BUILDINGS



PROPER EXPOSURE OF WIND SYSTEMS
IN BUILT-UP AREAS

FIGURE 12 4

5. Receptor location

   a. Distance perpendicular to highway
   b. Height above grade

D. General Flow Chart of Model

   1. See Figure 12-5

E. Outputs - estimates of <u>one</u> <u>hour</u> CO concentrations, above background levels

   1. Estimated CO concentration in PPM or ug/m^3 at receptor

   2. Estimated CO concentration in PPM or ug/m^3 in highway mixing cell.

IV. Limitations of CALINE2 Model

A. Aerodynamic effect of air flow for cut and fill sections.

B. Different surface roughness heights not considered in using σ's

C. Cannot handle zero wind speed (typical of all Gaussian Models - use 1 m/sec

D. Topographic effects of converging or diverging wind flow fields.

V. Advantages of CALINE2 Model

A. Simplicity

FLOW CHART FOR CALINE MODEL

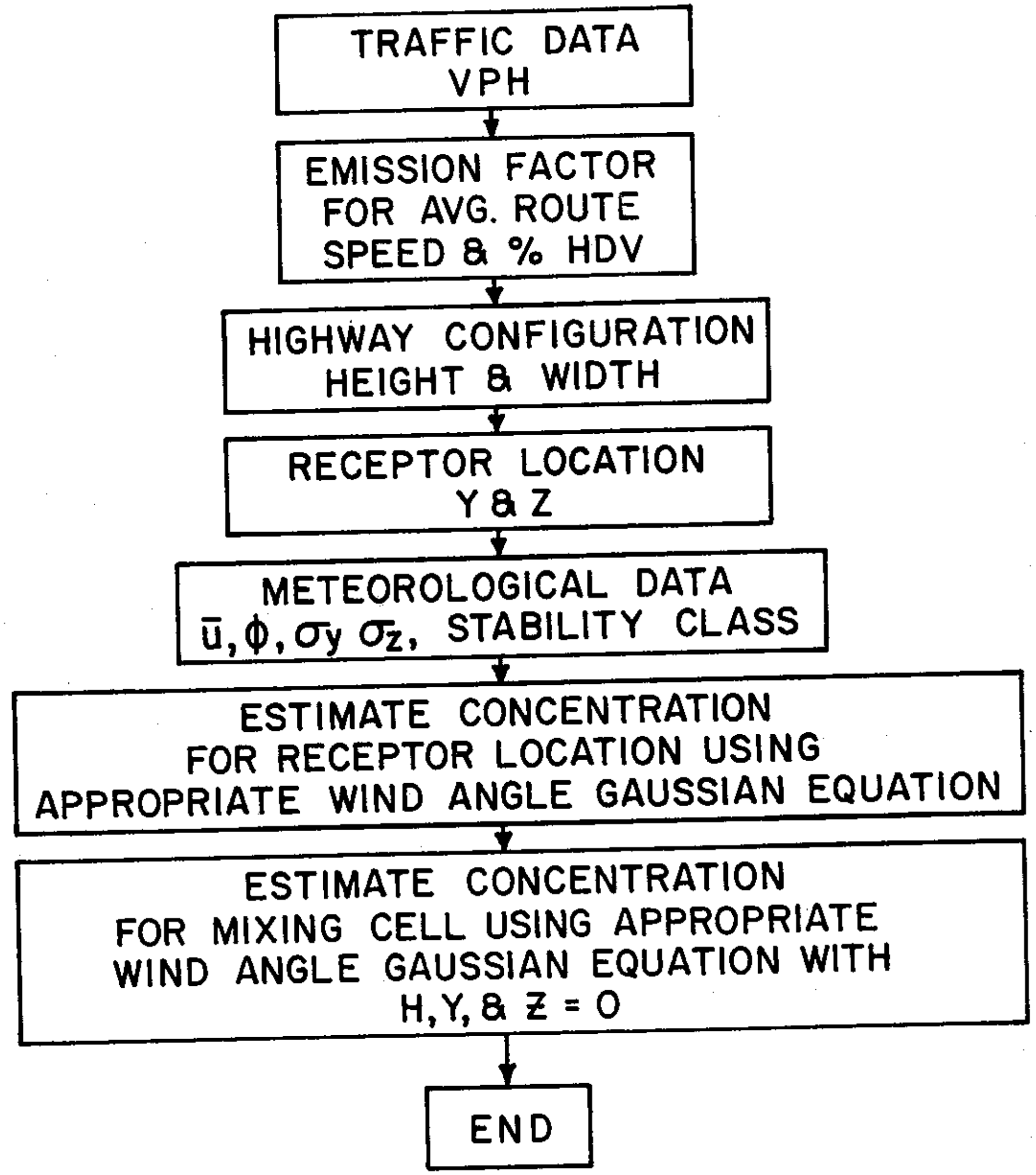


FIGURE 12-5

B. Practical model in terms of "real life". Can be used by Transportation Planners and Engineers.

C. Provides a basic foundation to understanding the fundamentals of transport and diffusion so that more advanced models can be used with confidence.

D. Computational efficiency

E. Presently performs as well as the more rigorous mathematical approaches.

VI. Review of older Line Source Model format

A. Gaussian Dispersion Theory combined with fixed box, as discussed previously.

B. Separated into two sub-models

1. Crosswind sub-model

a. Winds crossing the highway from normal (90°) to 12.5°

b. Uses only vertical dispersion parameter, since infinite line source has uniform horizontal (parallel to highway) distribution for crosswind

c. If other than 90°, factor of $1/\sin\phi$ is used

2. Parallel wind sub-model

a. Winds from parallel (0°) to 12.5° - assumes 0°

b. Sums up contributions from number of square area sources, since assumes that parallel wind causes concentrations to build up downwind.

3. 12.5° arbitrarily chosen as limiting condition for choosing sub-model.

C. Constant coefficients in original Gaussian Equations removed to cause overprediction or "safety factor".

D. Calibration coefficients (K)

1. Originally 4.24 to agree with New York field study data.

2. Later divided by 4.24 to nullify, since data from Los Angeles indicated original uncalibrated model predicted closer to field samples

3. FHWA requested other agencies to modify uncalibrated model predictions by 0.8 to agree with their investigatory data.

E. Empirical ratios developed to compensate for depressed highway sections

1. Creates imaginary mixing cell at level of top of depressed section, See Figure 12-6.

2. See Air Quality Manual Modification Number 1 at the end of this section.

CO REDUCTION FACTOR SCHEMATIC FOR DEPRESSED HIGHWAY SECTIONS

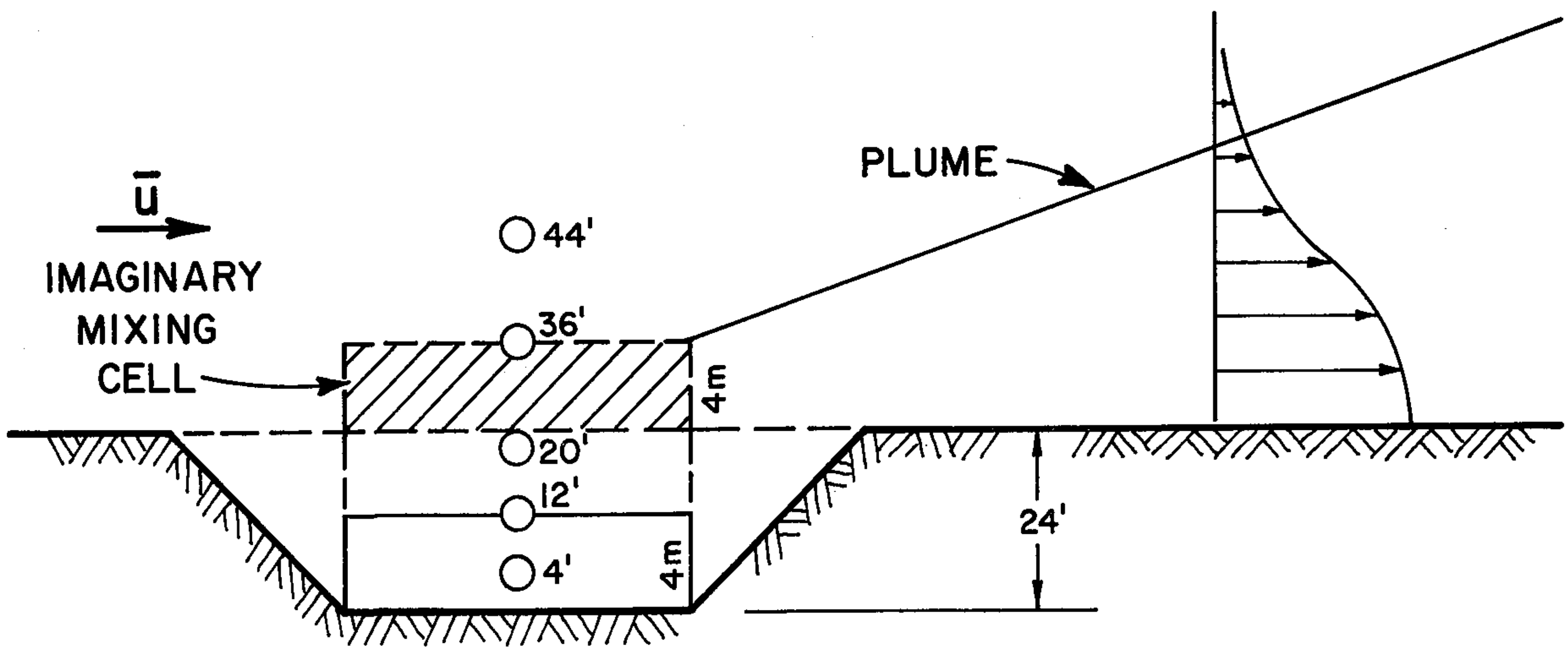


FIGURE 12-6

VII. Model Modifications - Development of CALINE2

A. Basic dispersion equations have been returned to original form, as discussed in Turner's "Workbook of Atmospheric Dispersion Estimates".

1. See Figure 12-7 and Figure 12-5.
2. Pure crosswind (90°) - infinite line source
3. Pure parallel wind (0°) - summation of area sources.

4. Concentrations for wind angles between 0° and 90° are calculated using weighted sum of crosswind and parallel wind equations.

5. Mixing Cell - solution of applicable equation(s) for highway height, receptor height, and receptor distance set equal to 0.

6. Constant coefficient of $2/\sqrt{2\pi}$ (for Z and H = 0) in crosswind equation approximately equals 0.8, therefore incorporate FHWA suggestion.

7. Calibration coefficients (K's) excluded.

8. Provides solid theoretical basis for other modifications.

B. Units of Model

1. C = pollutant concentration

BASIC CALINE2 MODEL EQUATIONS

1. GAUSSIAN - CROSSWIND (LINE SOURCE), $\phi = 90°$

$$C_1 = \frac{(\text{Fact})\ Q_1}{\sigma_z \bar{u} \sqrt{2\pi}} \left[\text{EXP}\left(-\frac{1}{2}\left(\frac{Z+H}{\sigma_z}\right)^2\right) + \text{EXP}\left(-\frac{1}{2}\left(\frac{Z-H}{\sigma_{z_i}}\right)^2\right) \right]$$

2. GAUSSIAN - PARALLEL WIND (POINT SOURCE), $\phi = 0°$

$$C_2 = \sum_{i=1}^{n} \frac{(\text{Fact})\ Q_2}{\sigma_{y_i} \sigma_{z_i} \bar{u} 2\pi} \left\{ \left[\text{EXP}\left(-\frac{1}{2}\left(\frac{Y}{\sigma_{y_i}}\right)^2\right) \right] \left[\text{EXP}\left(-\frac{1}{2}\left(\frac{Z+H}{\sigma_{z_i}}\right)^2\right) + \text{EXP}\left(-\frac{1}{2}\left(\frac{Z-H}{\sigma_{z_i}}\right)^2\right) \right] \right\}$$

WHERE n = INTEGER OF $\dfrac{\text{HIGHWAY DISTANCE PARALLEL TO WIND}}{W}$

3. GAUSSIAN - CROSSWIND, $0° < \phi < 90°$

$$C_3 = C_1 \ \text{SIN}^2 \phi + C_2 \ \text{COS}^2 \phi$$

4. BOX

$H, Y, Z = 0$

SOLVE FOR APPROPRIATE C USING ONE OF THE ABOVE EQUATIONS

FIGURE 12-7

2. Fact = conversion factor, to express C in appropriate units, e.g., to express C in PPM of CO,

$$\text{Fact} = \frac{0.0245}{\text{CO molecular wgt}} \times \frac{10^6 \text{ ug}}{\text{gm}} = 875$$

3. Q = source strength, in gm/m-sec or gm-m/m-sec.
   a. $Q_1 = (\text{fact}_2) \times EF \times VPH$
   b. $Q_2 = (\text{fact}_2) \times EF \times VPH \times W$
   c. $\text{Fact}_2 = 1.726 \times 10^{-7}$ mile-hr/m-sec

4. EF = average speed-corrected emission factor, in gms/mile

5. VPH = traffic volume, in vehicles/hour
6. W = highway width including all lanes, shoulders, and medians, in meters.
7. H = height of highway above or below grade, in meters
8. Z = height of receptor above grade, in meters

9. Y = perpendicular distance of receptor from edge of highway, in meters

10. $\bar{U}$ = average wind speed, in meters/sec
11. ϕ = average angle of wind to highway
12. σy = horizontal dispersion coefficient, in meters
13. σz = vertical dispersion coefficient, in meters

C. Empirical ratios for depressed sections are retained.

D. Parallel wind

1. Summation of area sources (See Figure 12-8)

   a. Highway divided into square area sources, with side length equal to the highway width.

SCHEMATIC SHOWING GENERAL GAUSSIAN DISPERSION OF POLLUTANTS FROM FIRST VIRTUAL POINT SOURCE UNDER PARALLEL WIND CONDITIONS

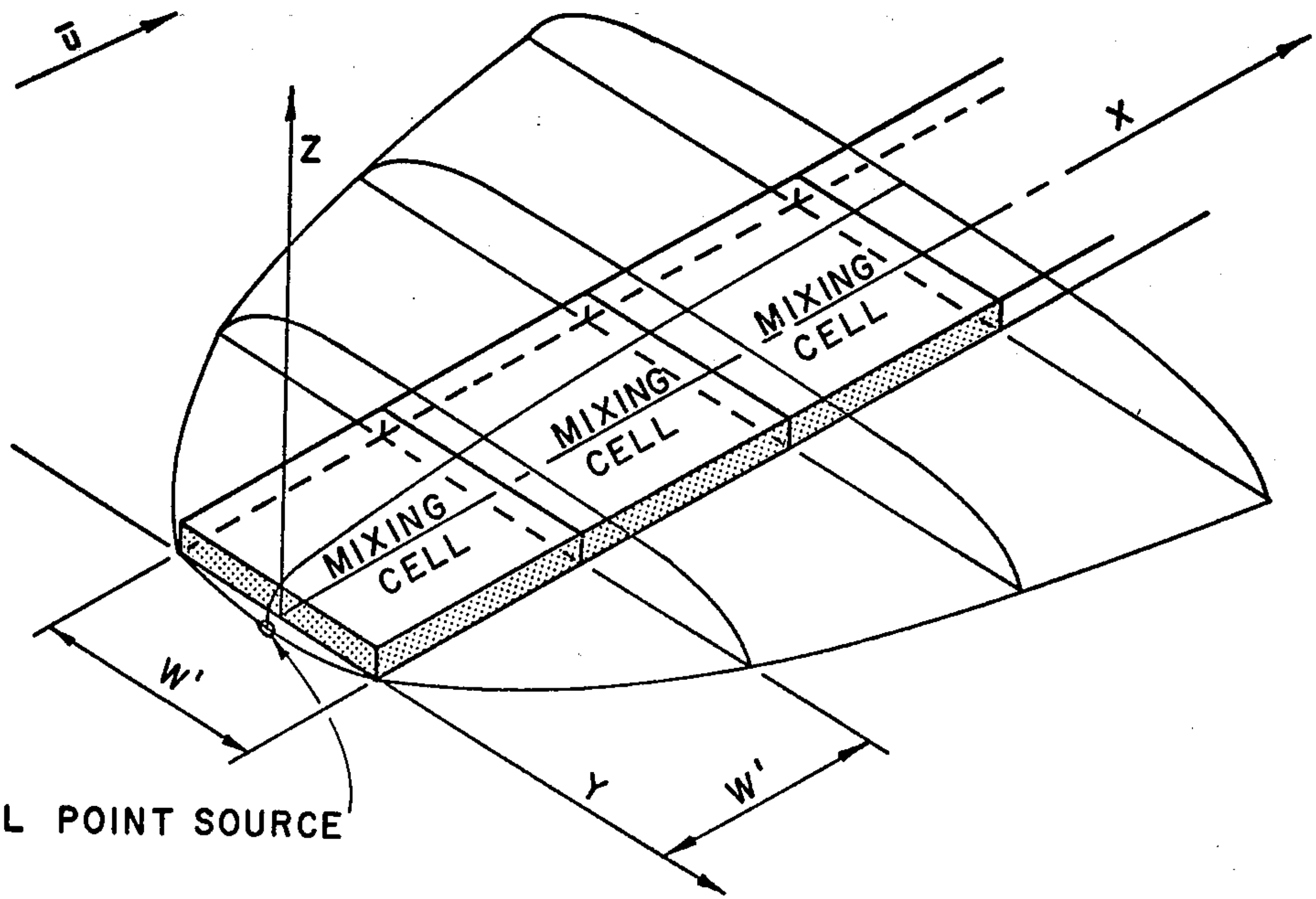


FIGURE 12-8

b. Area sources converted to equal number of point sources

(1) A distance back from the area source is calculated to locate a point source with equal source strength which will yield the initial horizontal dispersion (σ_y) at the upwind edge of the area source.

(2) This distance to the virtual point source is dependant on stability class and highway width.

(3) The dispersion at the upwind edge of the area source is assumed to be equal to the plume width ($4.3 * \sigma y$), therefore an estimate for σy is = width/4.3.

(4) The downwind distance corresponding to such a σy is found from the appropriate stability class horizontal dispersion parameter curve.

2. Concentration in parallel wind cell (area source) required to be equal to crosswind mixing cell concentration.

a. Comparison of equations indicated that a factor approximately equal to the virtual point source distance was required to make the equations equal, in magnitude and units.

b. Physical interpretation: The virtual point source distance is the distance the "Y" - axis is moved towards the highway centerline to artificially force the concentration at the highway edge to equal the mixing cell concentration.

3. Horizontal dispersion parameter (σ_y) curves (See Figure 12-9).

   a. Extrapolated to distance corresponding to highway width (= virtual point source distance)

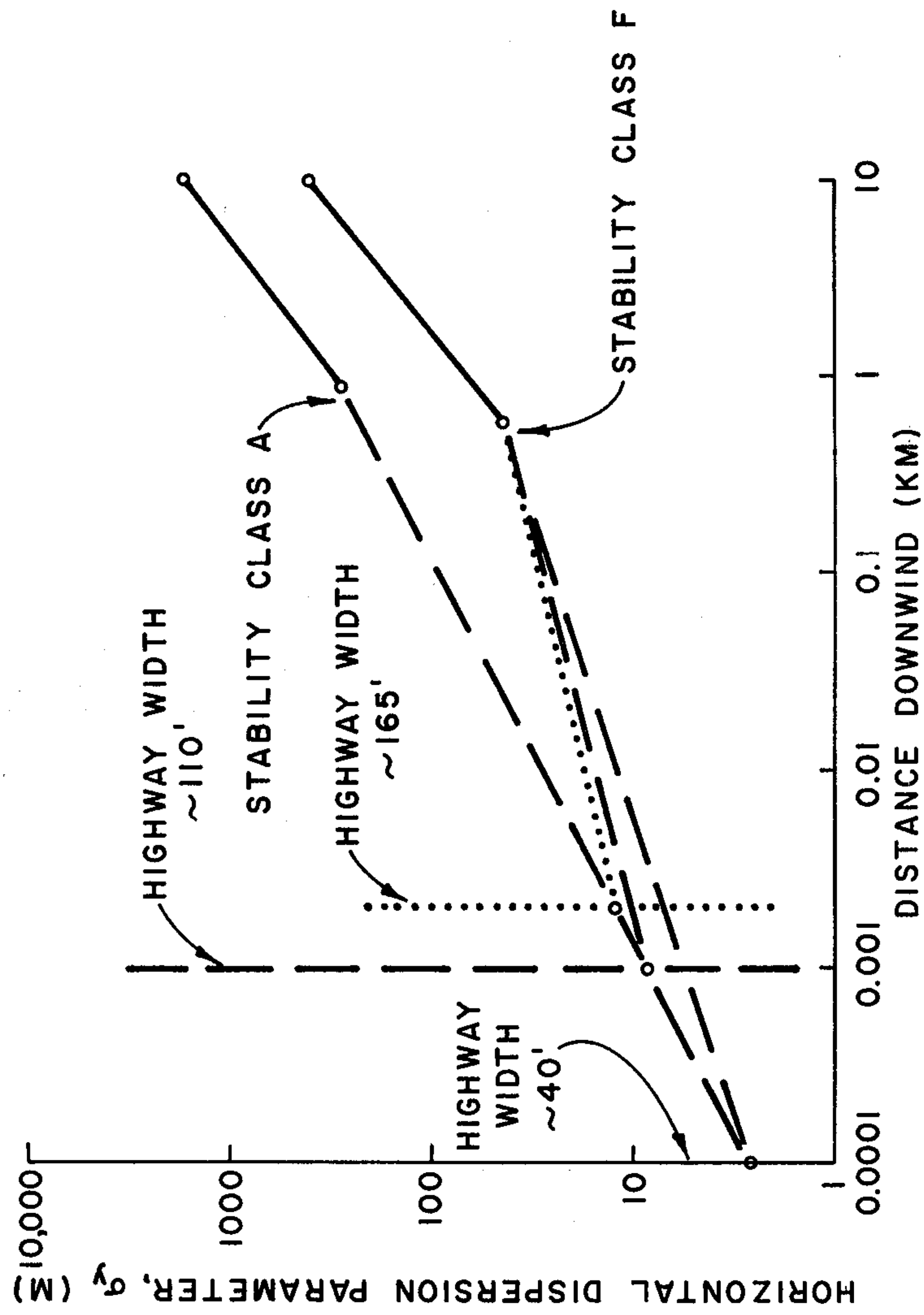
   b. σ_y at this point approximately equals the highway width divided by 4.3.

   c. Curves for all stability classes start at this point.

   d. Only first linear segment approximation of the curve is changed.

   e. Vertical dispersion parameter (σ_z) independent of highway width.

4. Scaling factor obtained from sensitivity analysis (See Figure 12-18) yields pollutant concentration corresponding to essentially "infinite" parallel wind highway segment, from the concentration calculated for a short (1/2 mile) parallel wind highway segment.



MODIFICATION OF σ_y FOR VARIATIONS IN HIGHWAY WIDTH

FIGURE 12-9

a. Fewer area sources or integration steps so that computer time is minimal.

b. Allows comparison of crosswind and parallel wind results.

D. Crosswind

1. 90° is "pure" equation

2. $0° < \text{wind angle} < 90°$ requires calculation and sum of "pure" crosswind and "pure" parallel wind components.

3. Influence of each component depends on angle.

4. Now have continuous function between 0° and 90° no discontinuity at 12.5°.

5. Eliminates $1/\sin\phi$ factor which allowed wind speed component to become smaller than the model's limit for wind speed.

VIII. Sensitivity Analysis

A. Variation in Predicted CO levels due to variation of input parameter.

B. Base case

1. Arbitrarily chosen as "typical" day
2. 6-lane highway - approximately 120' wide
3. Average usage - 6000 vehicles/hour
4. Neutral conditions - stability class "D", wind speed 3 mph
5. Completely parallel (0°) or crosswind (90°) wind angle
6. Emission factor of 25 gms/mile

7. At-grade highway
8. Mixing Cell Receptor
9. Parallel wind highway length of 1/2 mile

C. Vehicle/hour, See Figure 12-10
D. Emission factor, See Figure 12-11
E. Wind Speed, See Figure 12-12
F. Wind Angle, See Figures 12-13 and 12-14
G. Stability Class, See Figure 12-15
H. Pavement Height, See Figure 12-16
I. Highway width, See Figure 12-17
J. Highway length with parallel wind, See Figure 12-18
K. Horizontal and vertical dispersion parameters, See Figure 12-19

IX. Model Validation

A. Spatial distribution of pollutants

1. CO, Figures 12-20 through 12-29
2. Particulates, Figure 12-30
3. NO_x, Figures 12-31 and 12-32
4. HC, Figure 12-33

B. Model validation flow chart, Figure 12-34

C. Validation of CALINE2 by sample site (with comparisons to older model's regressions), See Figures 12-35 through 12-54.

D. Validation of AeroVironment Model, Figures 12-55 through 12-58.

E. Validation of S^3 Model, Figures 12-59 through 12-62.

X. AeroVironment Line Source Model: April and August 1972 Validation for Carbon Monoxide

A. Inputs to Model Include:

1. $\overline{U}$
2. $\emptyset$
3. Radiation Flux (set to zero)
4. Reference Roughness (.1m)
5. Actual Roughness (.5m)
6. Ratio of Vertical to Horizontal Dispersion Speeds (.32)
7. VPH
8. EF (set to 15 grams/mile = 50 mph)
9. Background Level
10. Coordinates of Plane $\perp$ to Road Segment

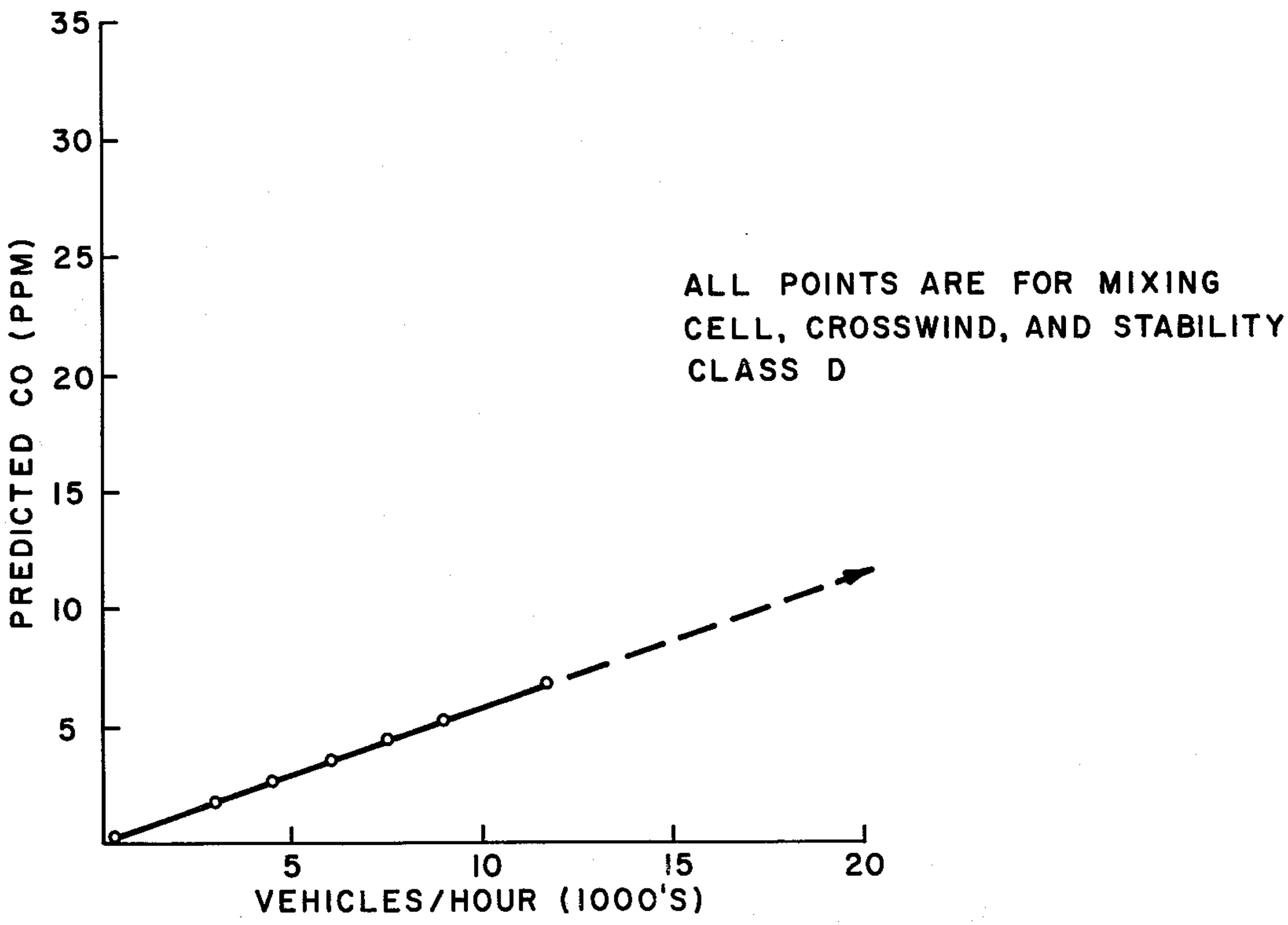
B. Variables Unusual to Most Line Source Models

1. Roughness
2. Ratio of Dispersion Speeds
3. Radiation Flux (very sensitive)

XI. SYSTEM SCIENCE AND SOFTWARE, S^3

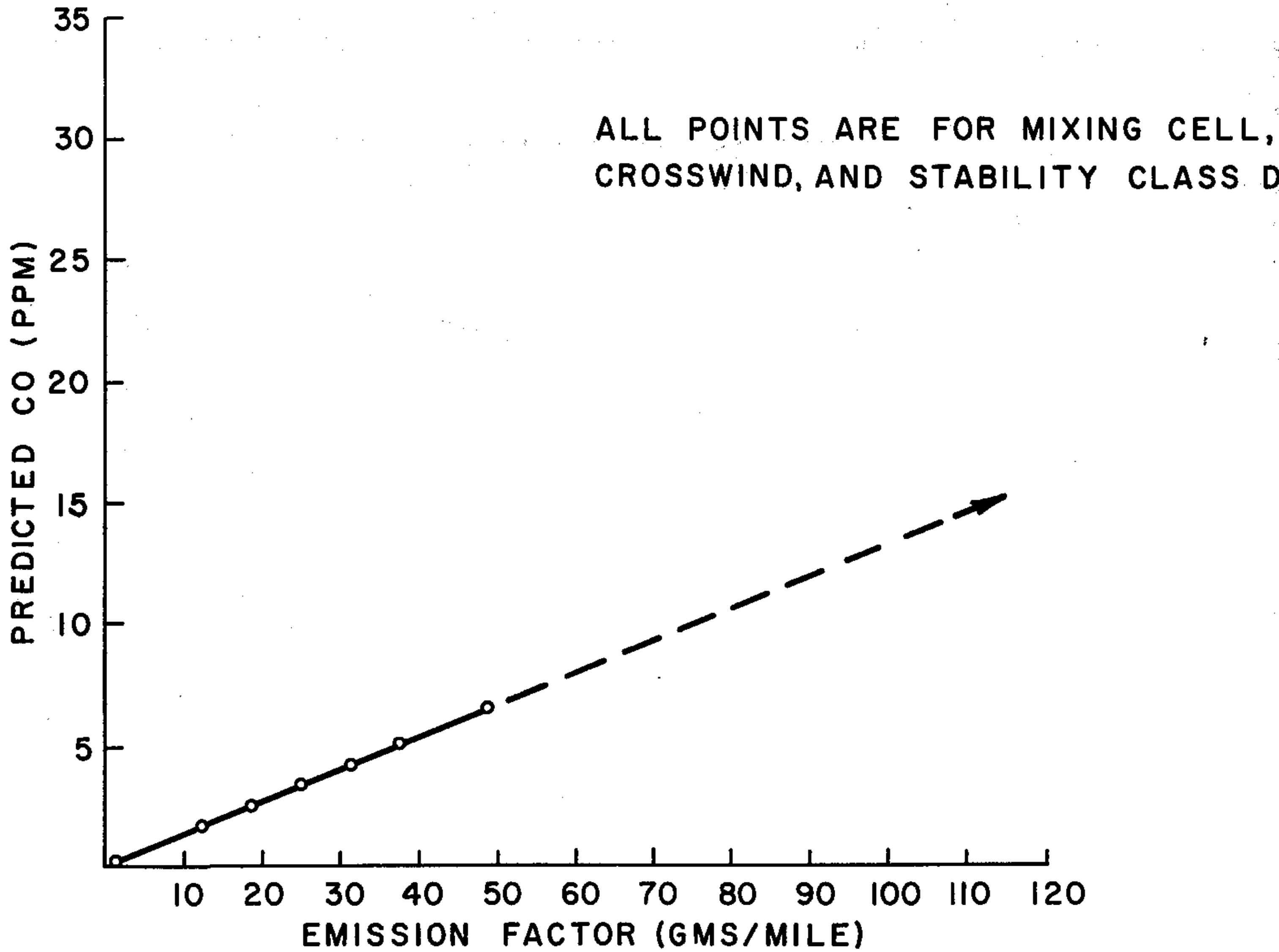
A. Inputs

1. Grid height and length
2. Roadway height and width
3. Stability Class
4. Wind profile
5. Diffusivities
6. Terrain features
7. Windspeed and direction
8. Emission factors
9. Vehicles per hour



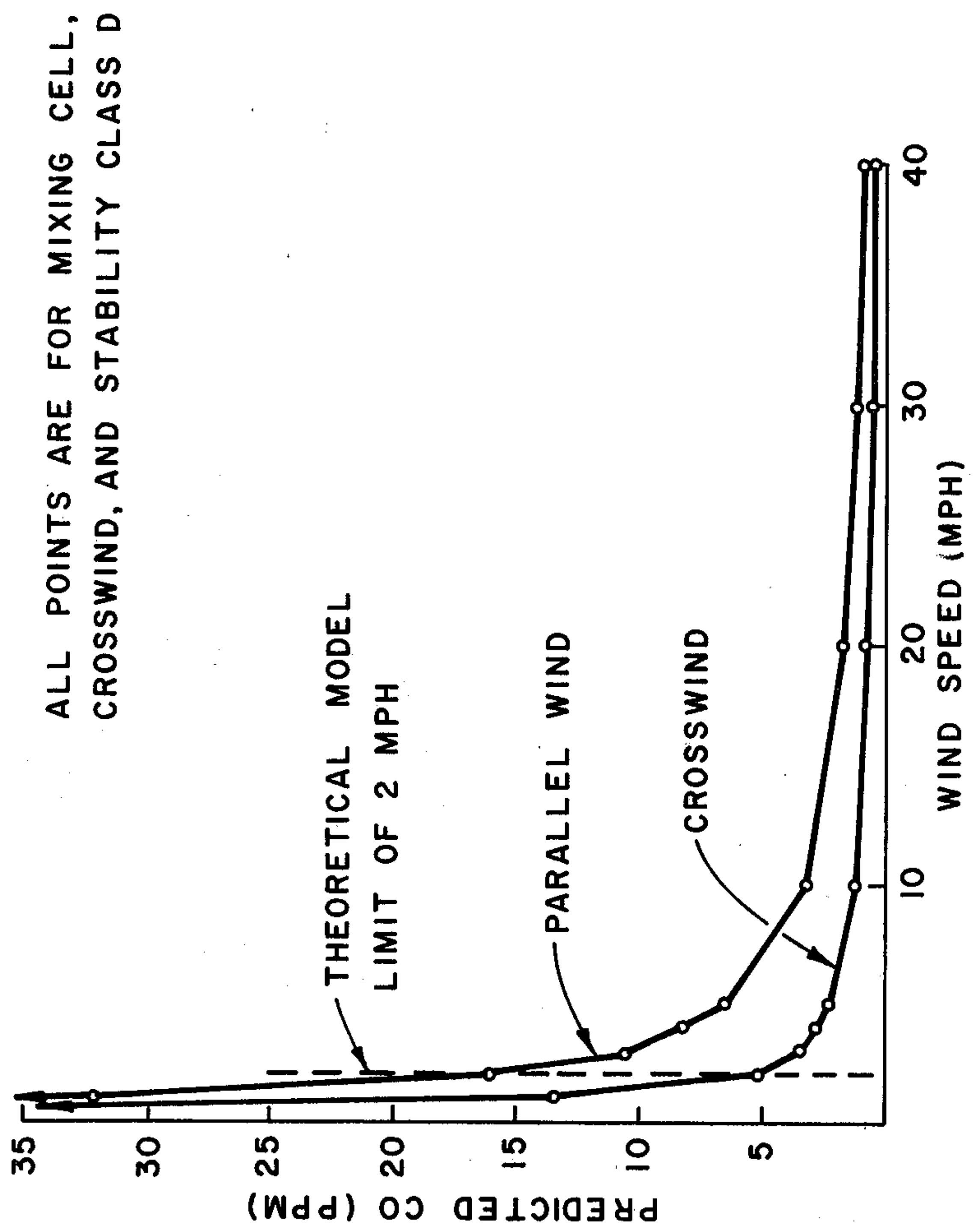
CALINE 2 SENSITIVITY TO VEHICLES PER HOUR

Figure 12-10



CALINE 2 SENSITIVITY TO EMISSION FACTOR

FIGURE 12-11



CALINE 2 SENSITIVITY TO WIND SPEED

FIGURE 12-12

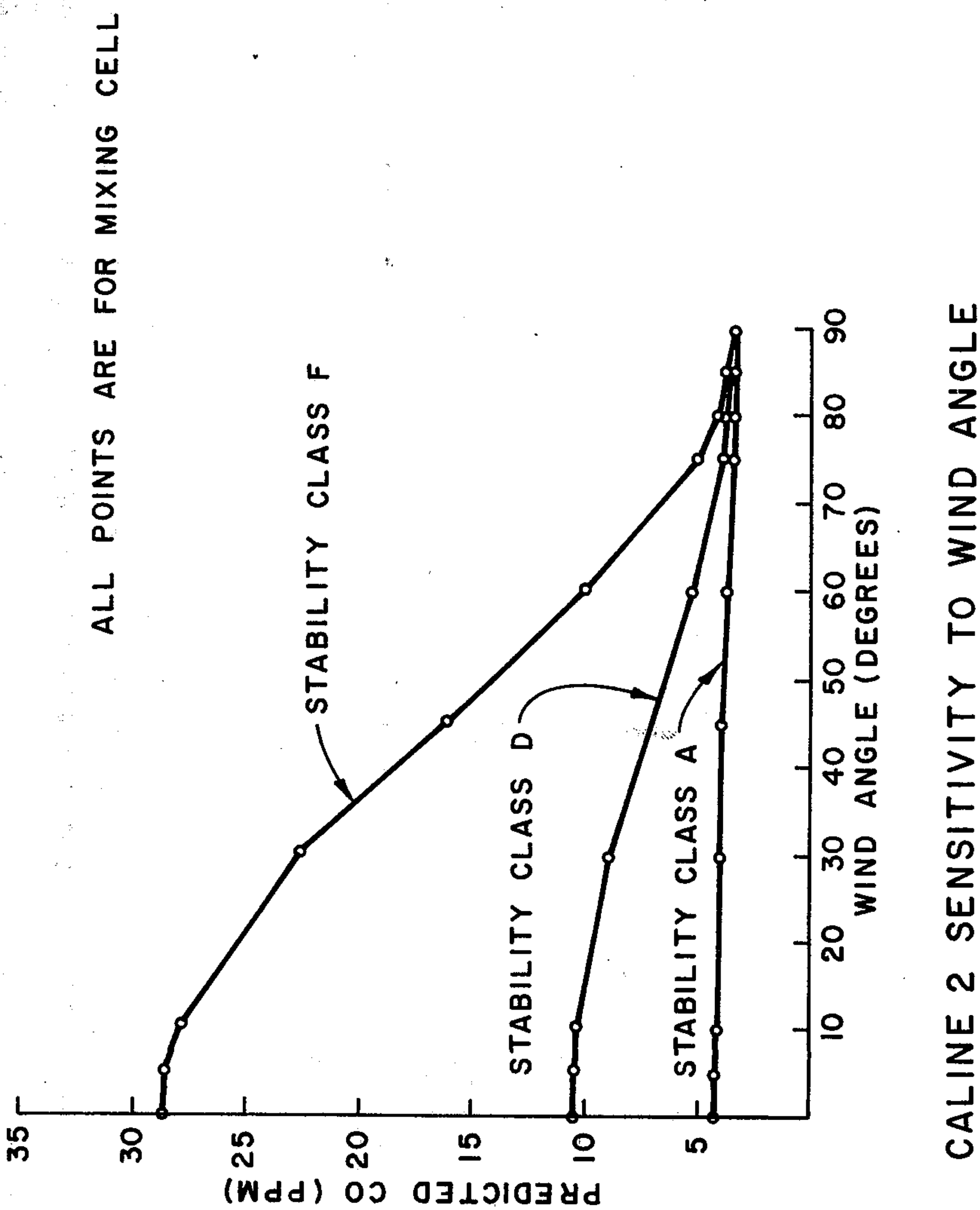

ALL POINTS ARE FOR MIXING CELL
STABILITY CLASS F
STABILITY CLASS D
STABILITY CLASS A
PREDICTED CO (PPM)
35
30
25
20
15
10
5
10
20
30
40
50
60
70
80
90
WIND ANGLE (DEGREES)
CALINE 2 SENSITIVITY TO WIND ANGLE

Figure 12-13

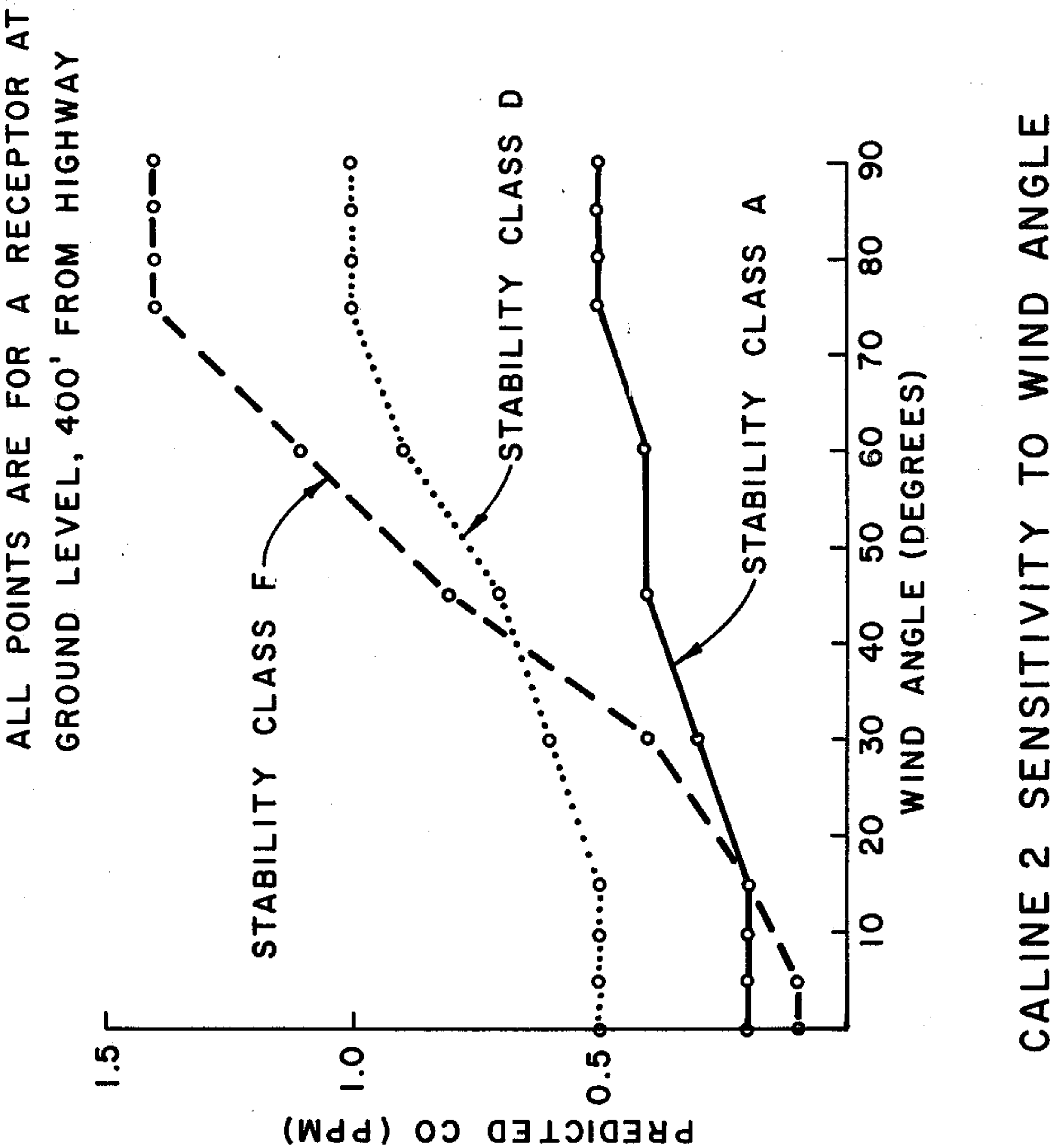
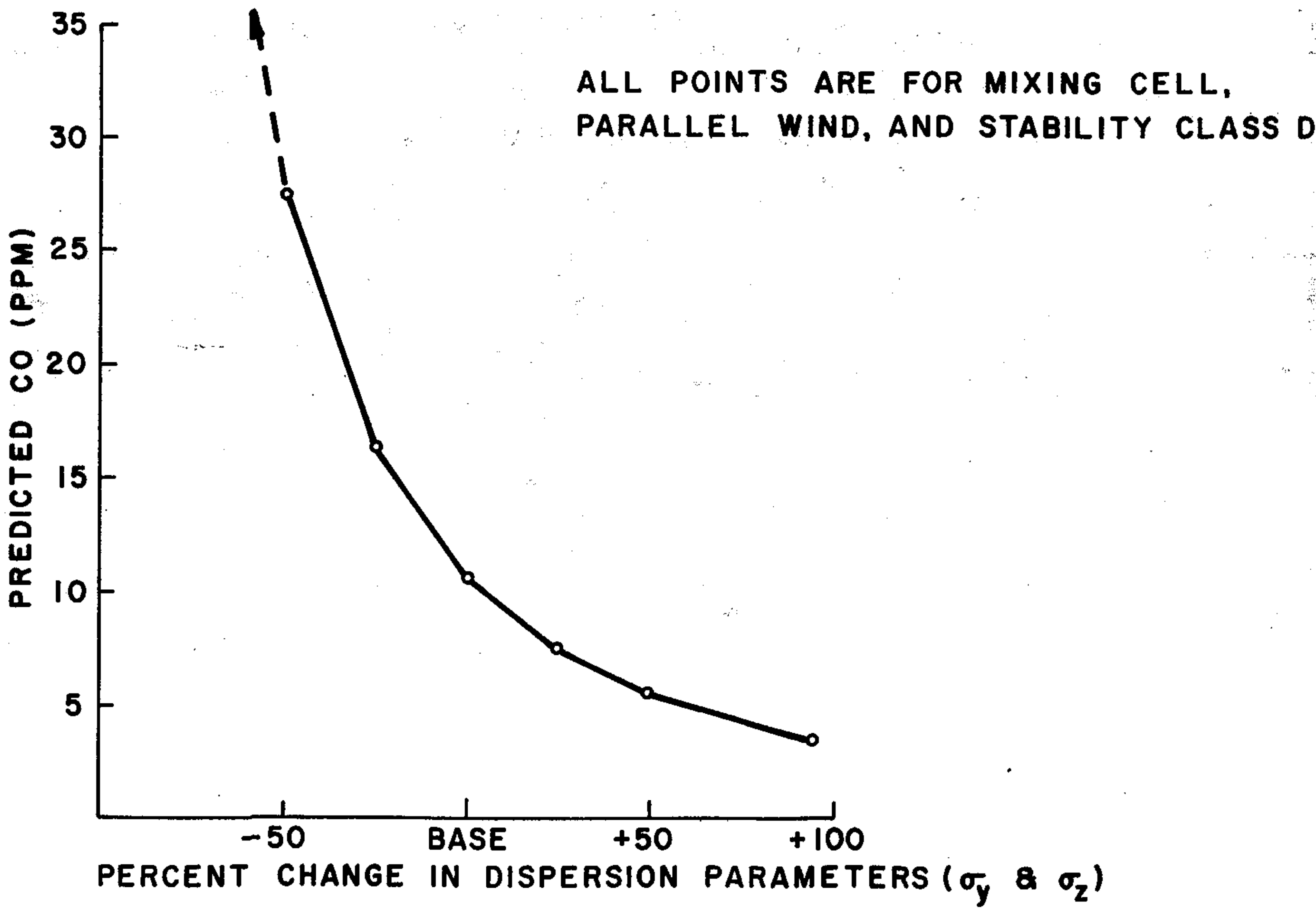
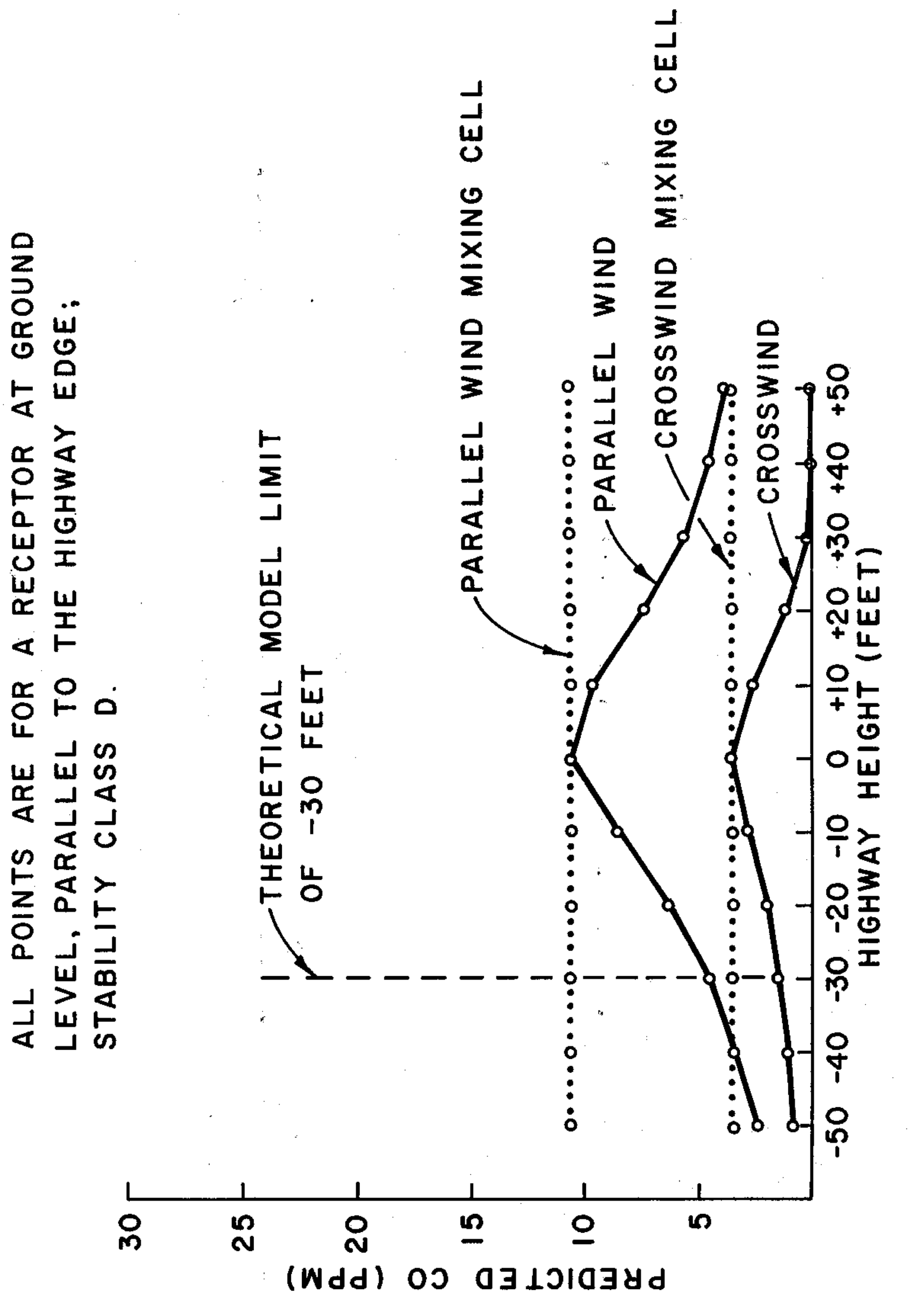

ALL POINTS ARE FOR A RECEPTOR AT GROUND LEVEL, 400' FROM HIGHWAY
STABILITY CLASS F
STABILITY CLASS D
STABILITY CLASS A
PREDICTED CO (PPM)
1.5
1.0
0.5
10
20
30
40
50
60
70
80
90
WIND ANGLE (DEGREES)
CALINE 2 SENSITIVITY TO WIND ANGLE

FIGURE 12-14



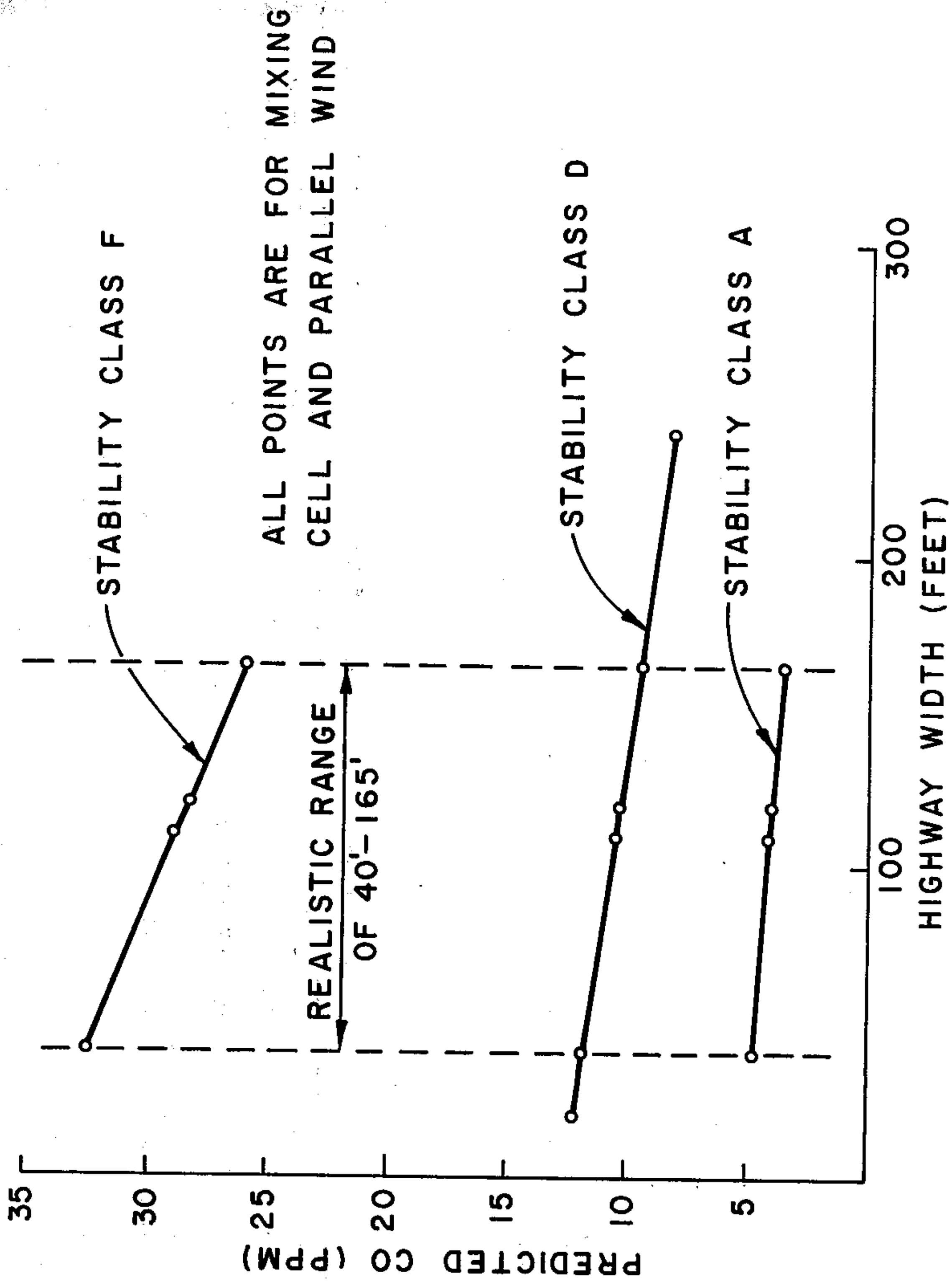
CALINE 2 SENSITIVITY TO DISPERSION PARAMETERS

FIGURE 12-15



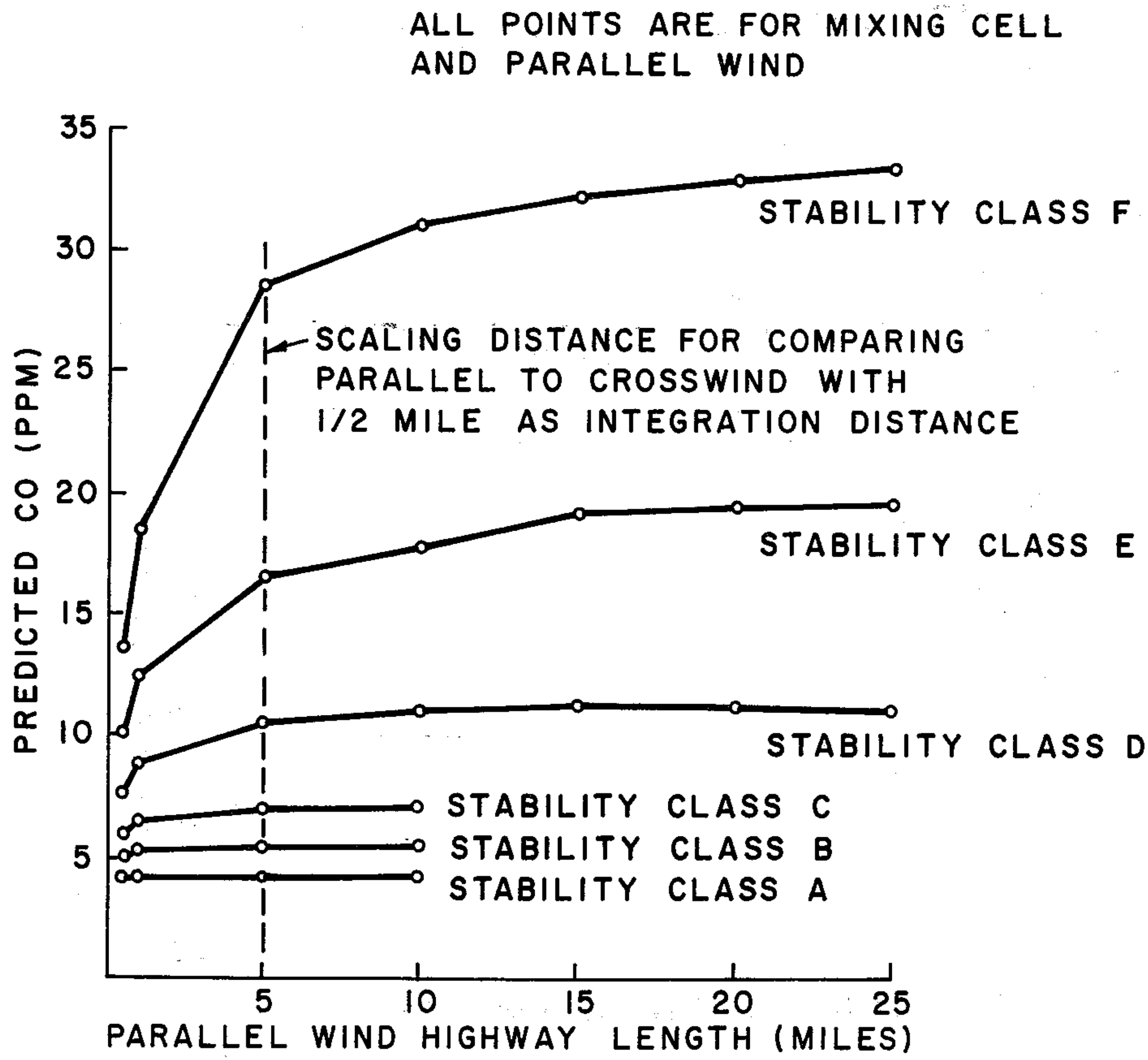
CALINE 2 SENSITIVITY TO HIGHWAY HEIGHT

FIGURE 12-16



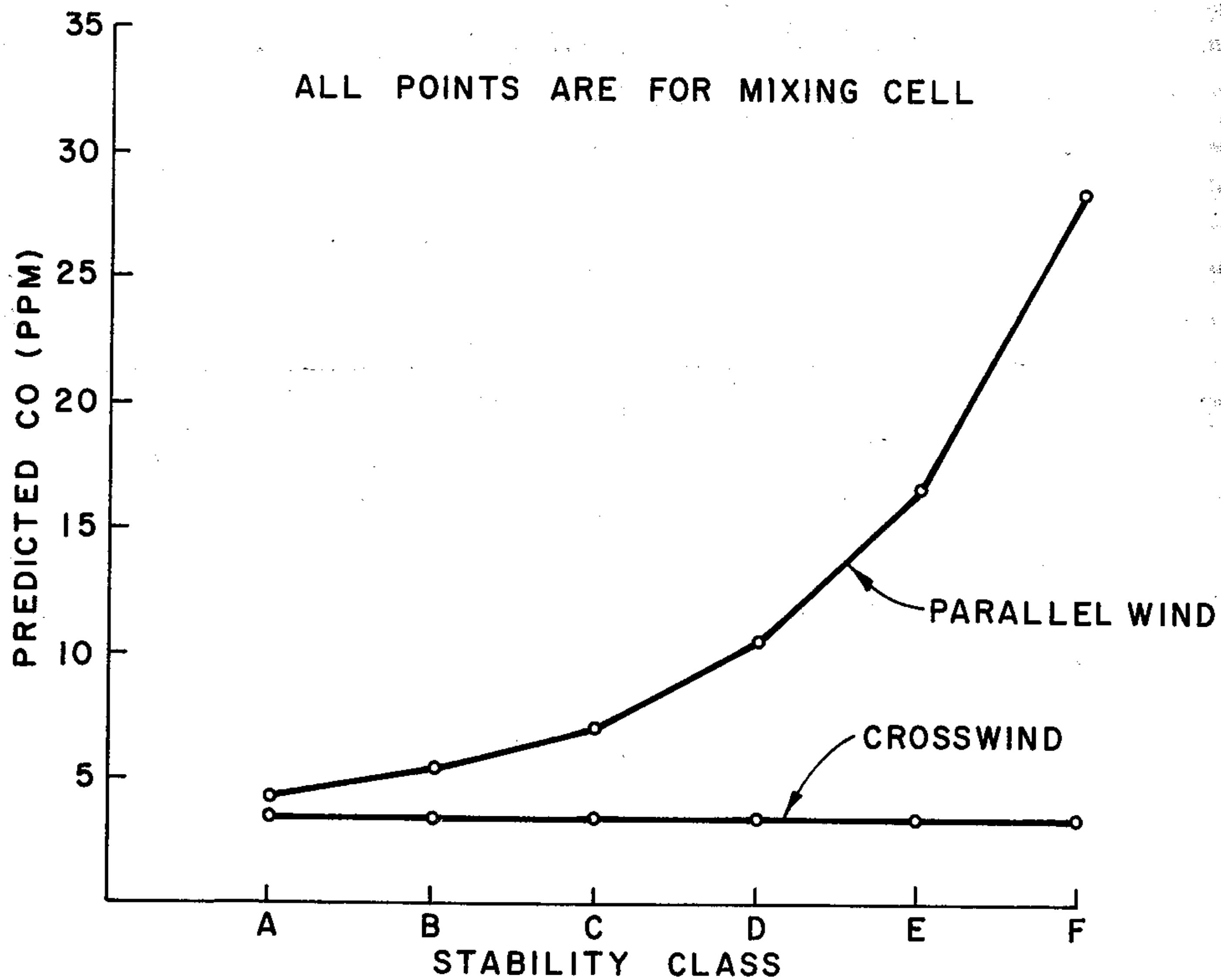
CALINE 2 SENSITIVITY TO HIGHWAY WIDTH

FIGURE 12-17



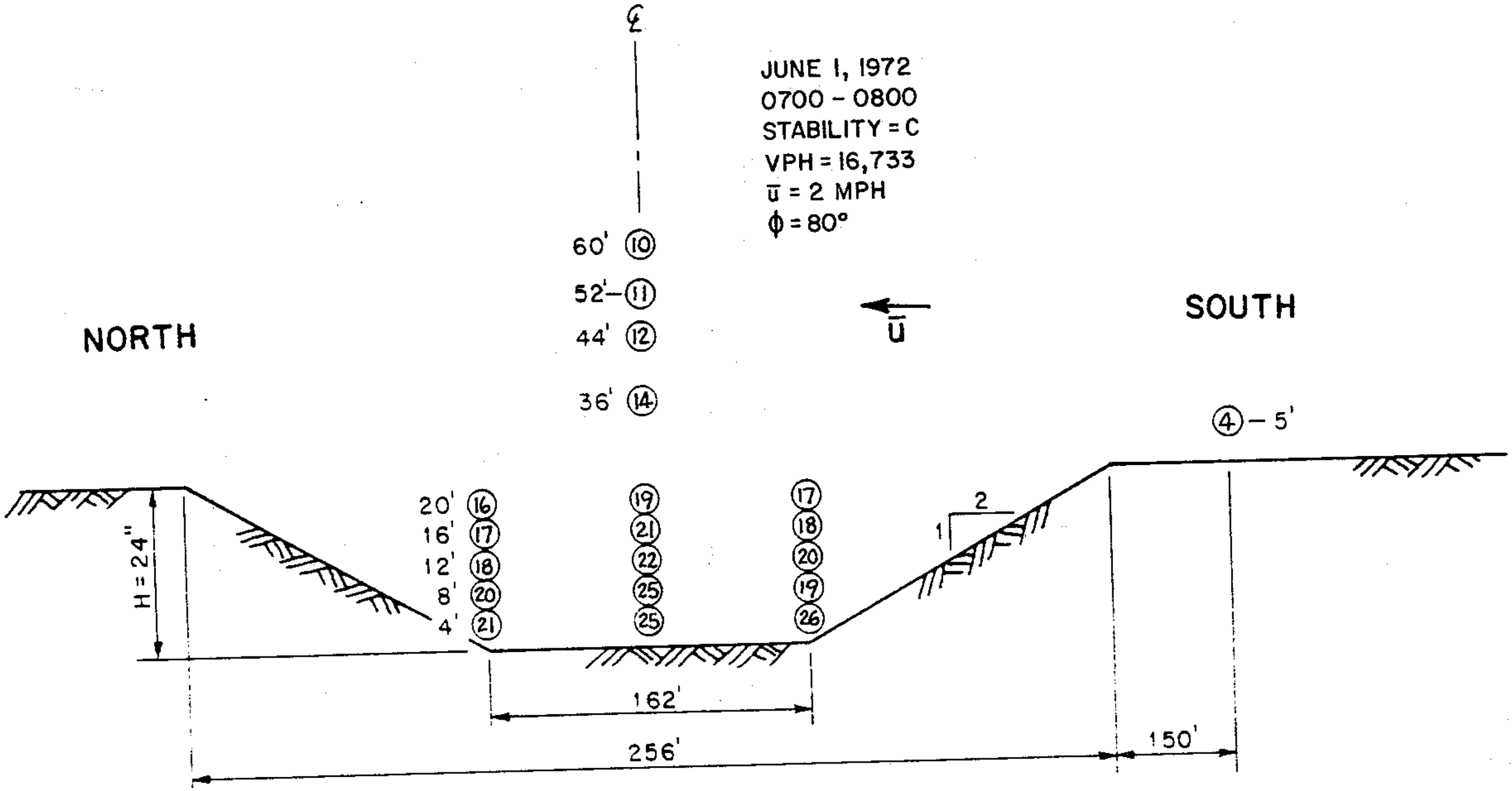
CALINE 2 SENSITIVITY TO
HIGHWAY LENGTH PARALLEL TO WIND

FIGURE 12-18



CALINE 2 SENSITIVITY TO STABILITY CLASS

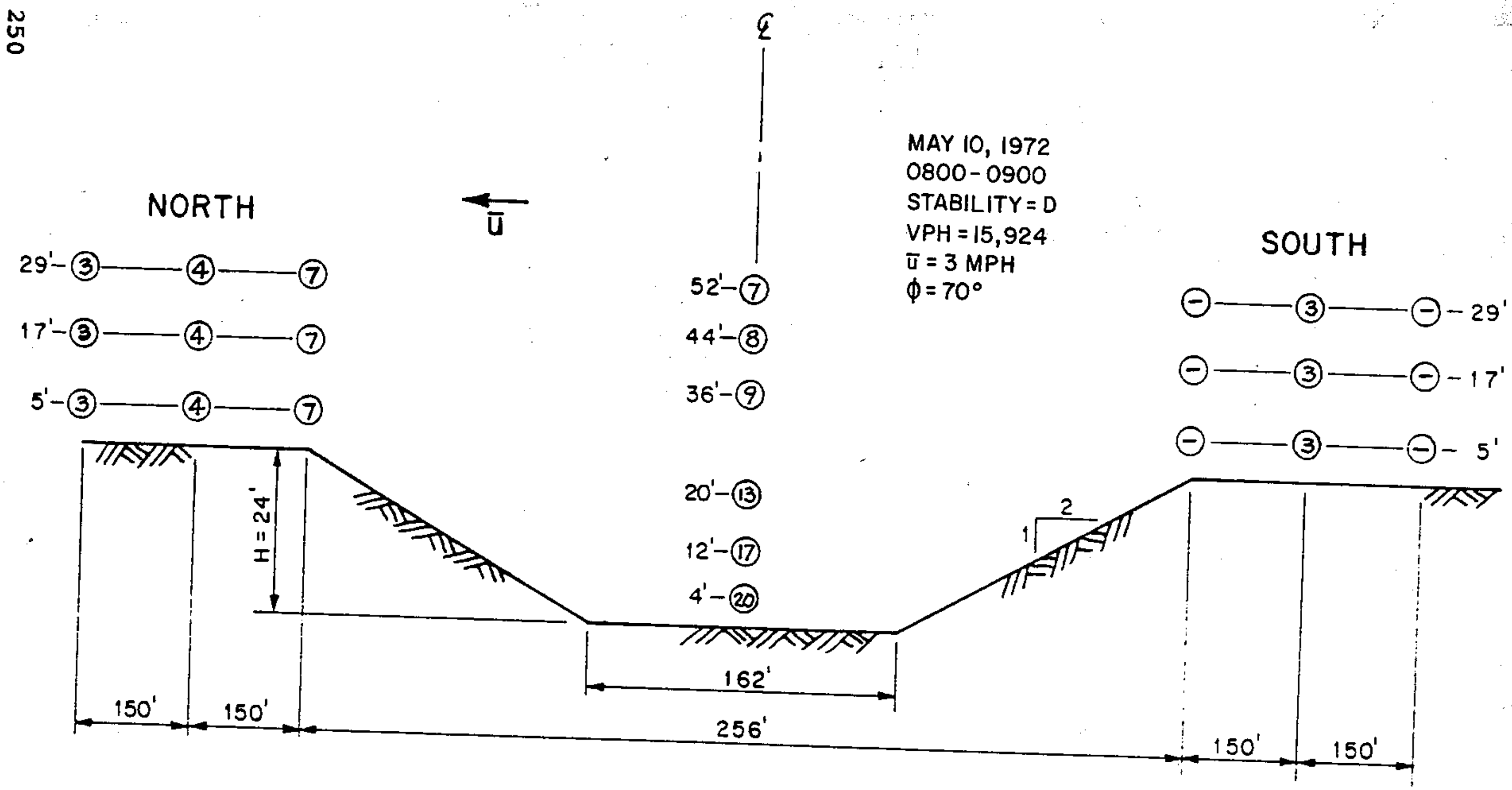
Figure 12-19



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 2-STORY HOUSES

CROSSWIND CO CONCENTRATIONS SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. IN-SECTION STUDY

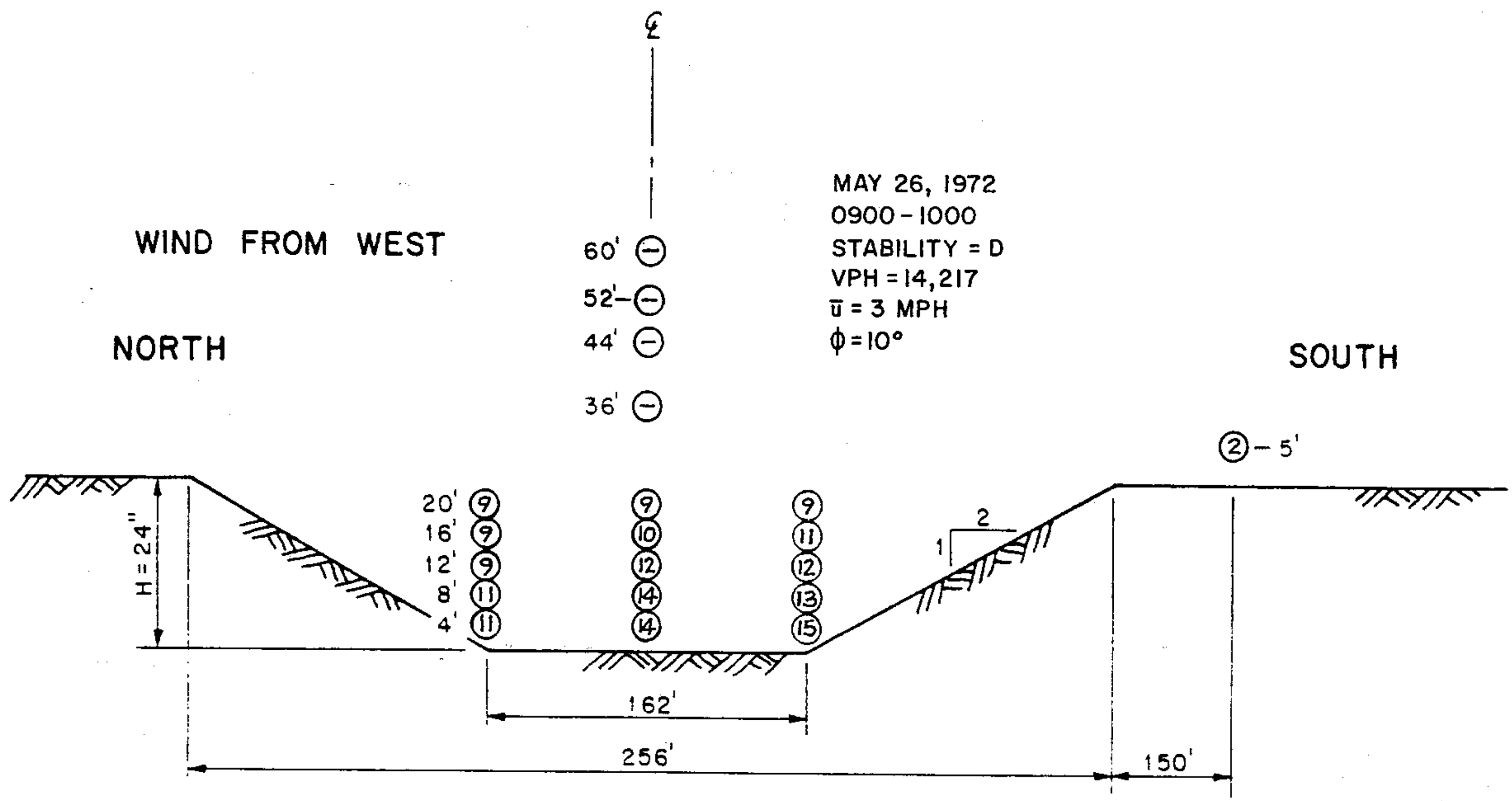
FIGURE 12-20



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 2-STORY HOUSES

CROSSWIND CO CONCENTRATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. DOWNWIND STUDY

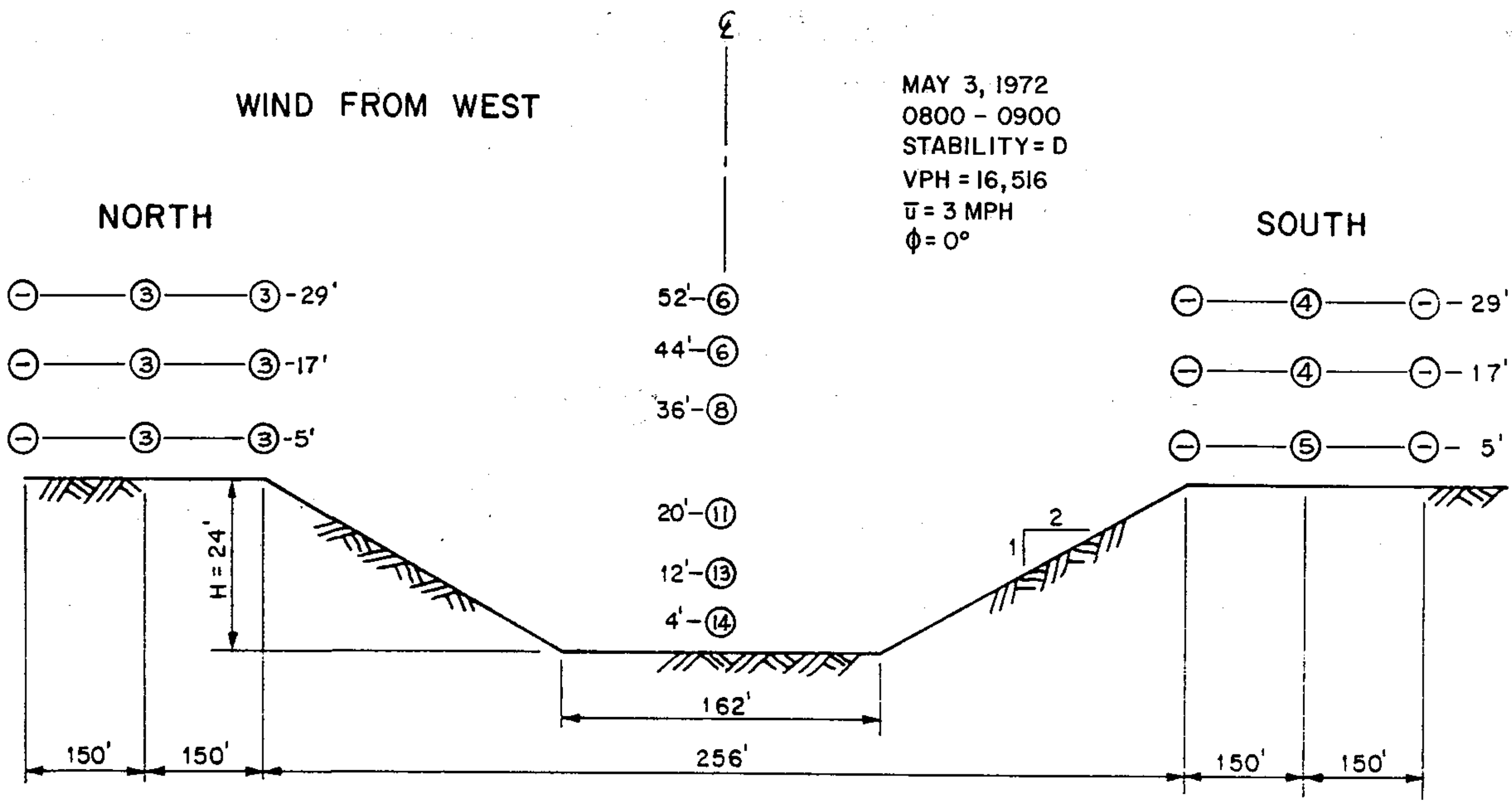
FIGURE 12-21



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 2-STORY HOUSES

PARALLEL WIND CO CONCENTRATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. IN-SECTION STUDY

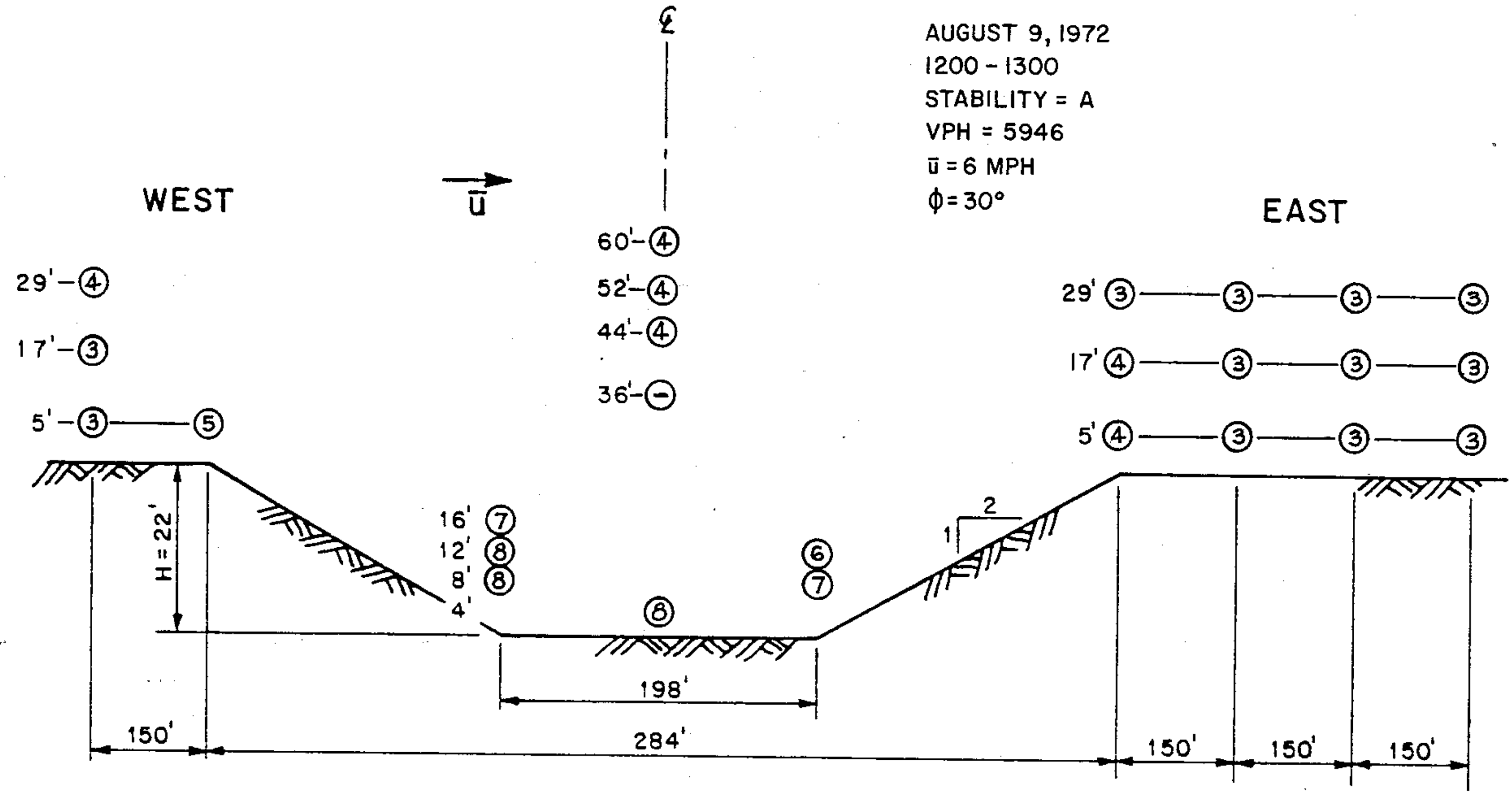
FIGURE 12-22



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 2-STORY HOUSES

PARALLEL WIND CO CONCENTRATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. HORIZONTAL STUDY

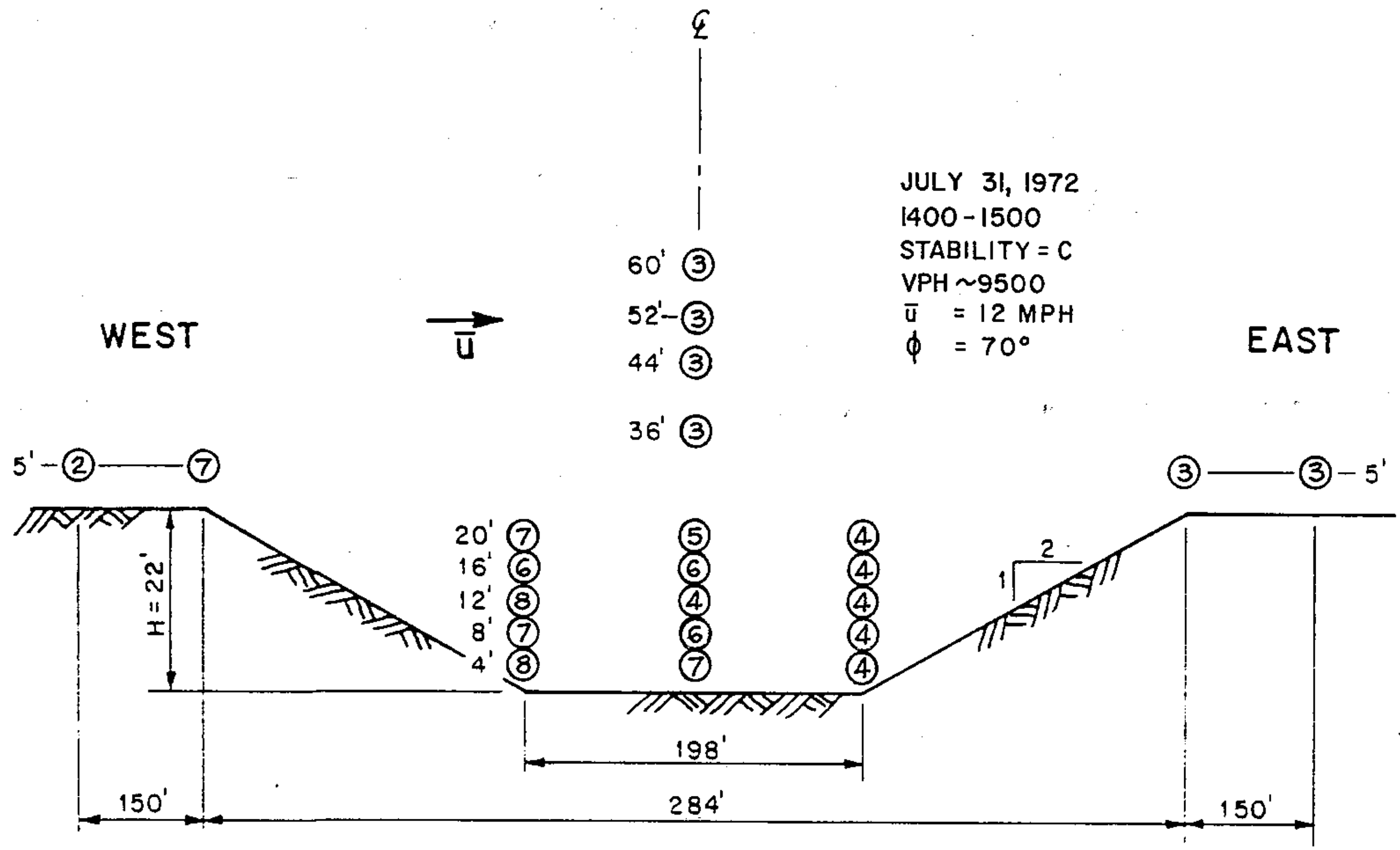
FIGURE 12-23



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 1-STORY HOUSES

CROSSWIND CO CONCENTRATIONS HARBOR FREEWAY
AT146TH AVE HORIZONTAL STUDY

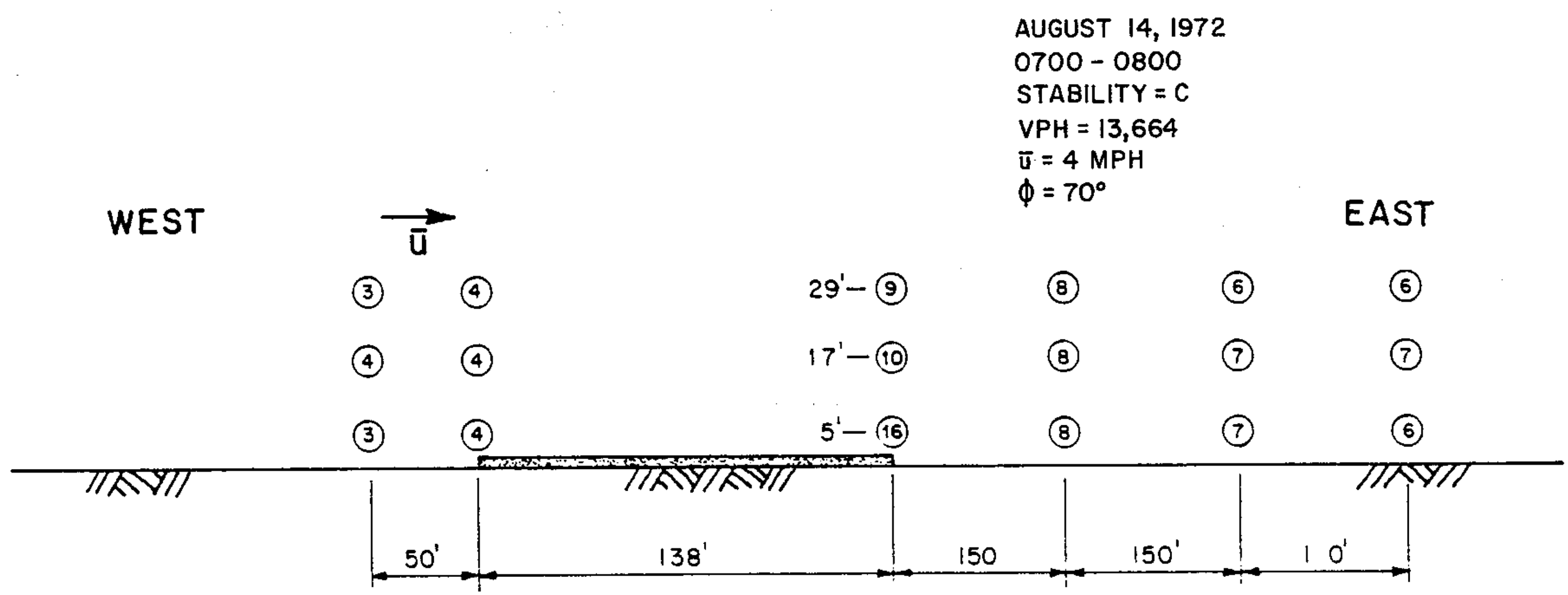
FIGURE 12-24



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 1-STORY HOUSES

CROSSWIND CO CONCENTRATIONS, AERODYNAMIC EDDIES, HARBOR FREEWAY
AT 146TH AVE IN-SECTION STUDY

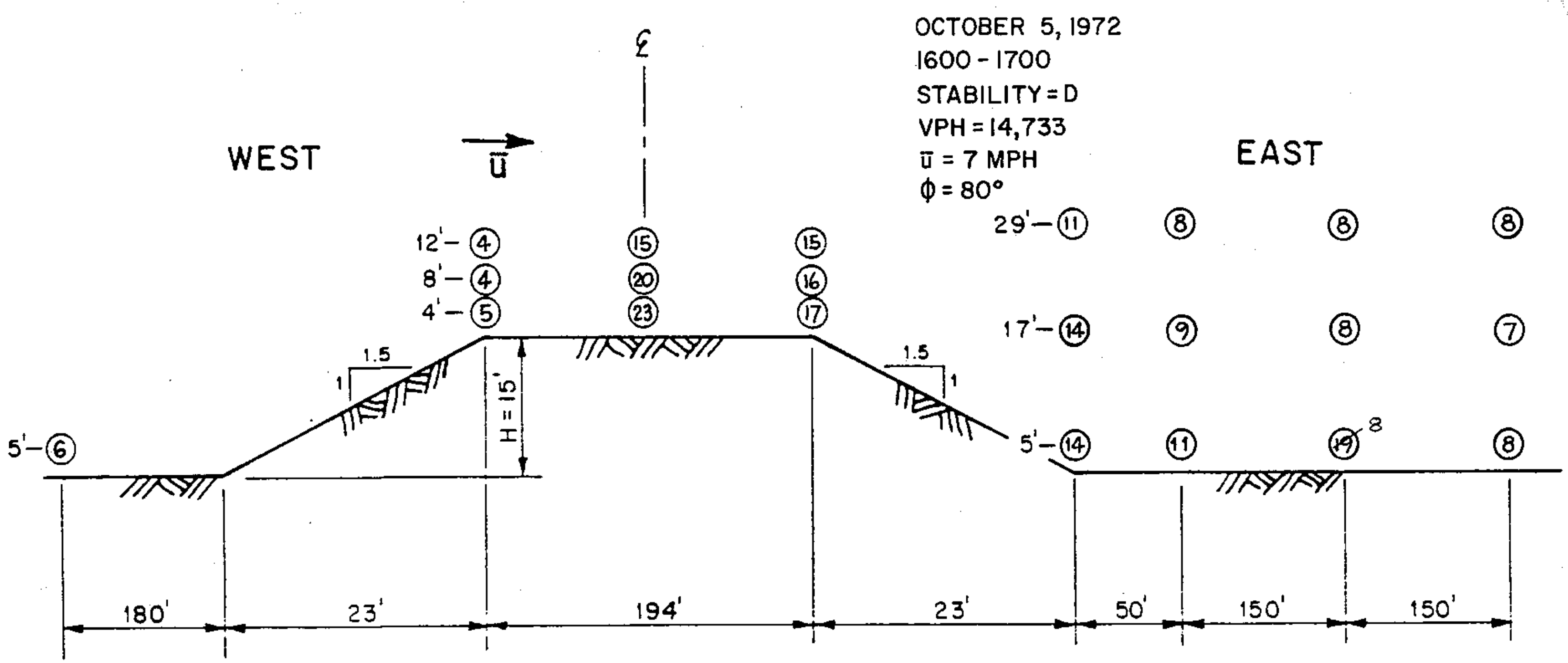
FIGURE 12-25



SURFACE ROUGHNESS CHARACTERISTICS
FLAT, OPEN FIELD

CROSSWIND CO CONCENTRATIONS SAN DIEGO FREEWAY
AT WEIGH STATION, AUGUST HORIZONTAL STUDY

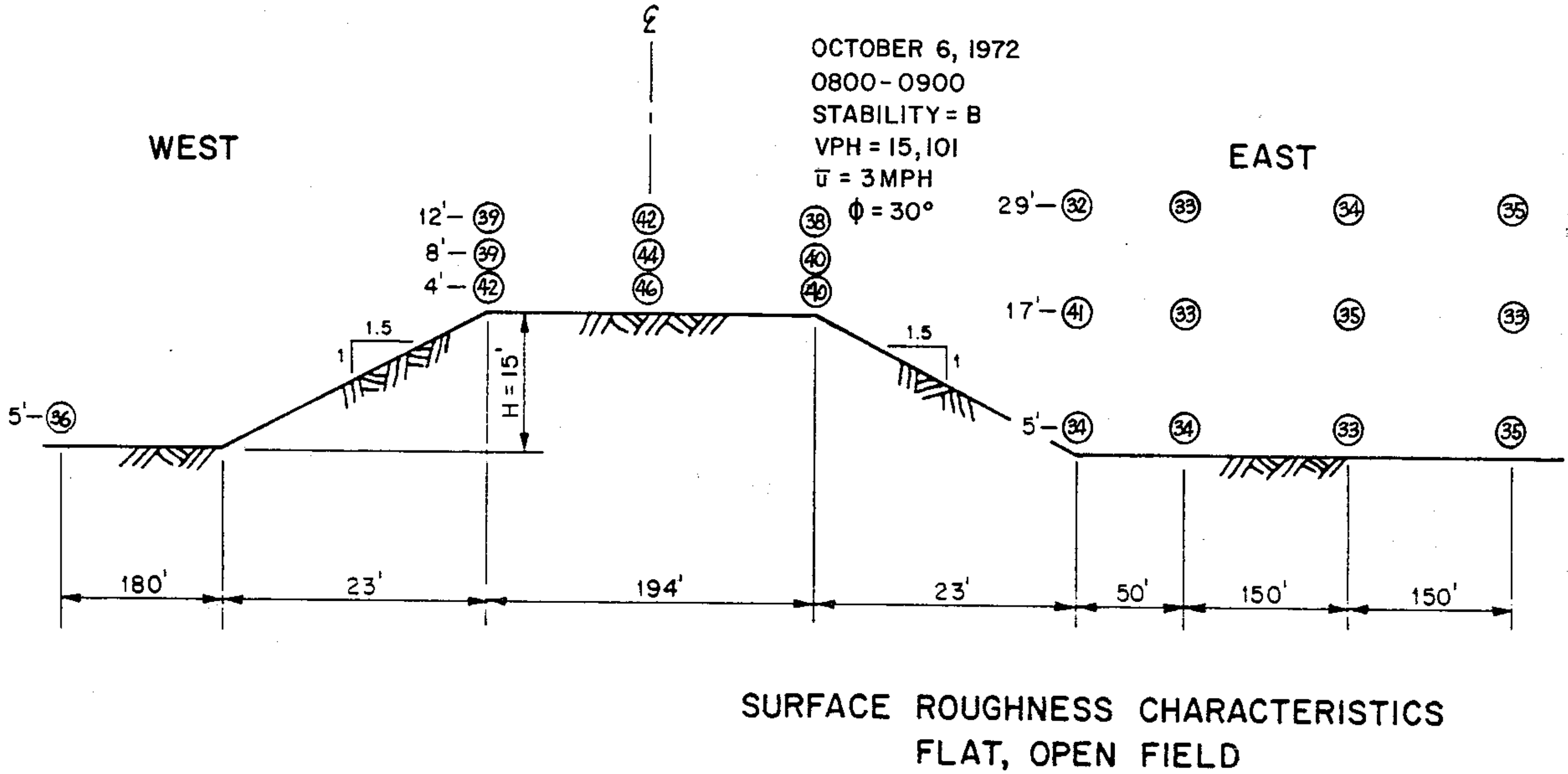
FIGURE 12-26



SURFACE ROUGHNESS CHARACTERISTICS
FLAT, OPEN FIELD

CROSSWIND CO CONCENTRATIONS, SAN DIEGO FREEWAY
AT 122ND AVE HORIZONTAL STUDY

FIGURE 12-27

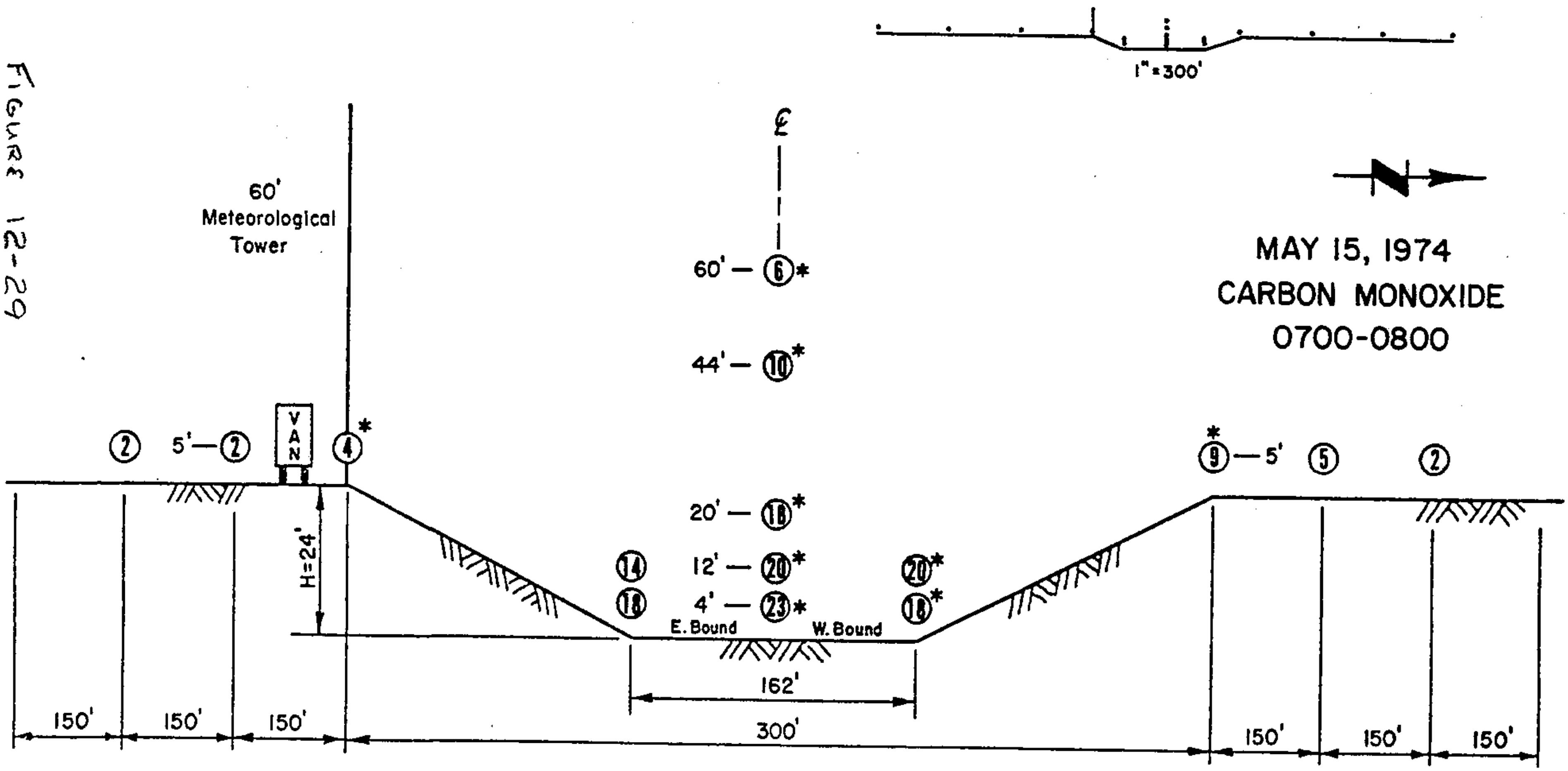


CROSSWIND CO CONCENTRATIONS, SAN DIEGO FREEWAY
AT 122ND AVE HORIZONTAL STUDY

FIGURE 12.2B

PROBE LOCATIONS
SANTA MONICA FWY @ 4th AVE. P.O.C.

MAY 15, 1974
CARBON MONOXIDE
0700-0800



* Probes for bag box

FIGURE 12-29

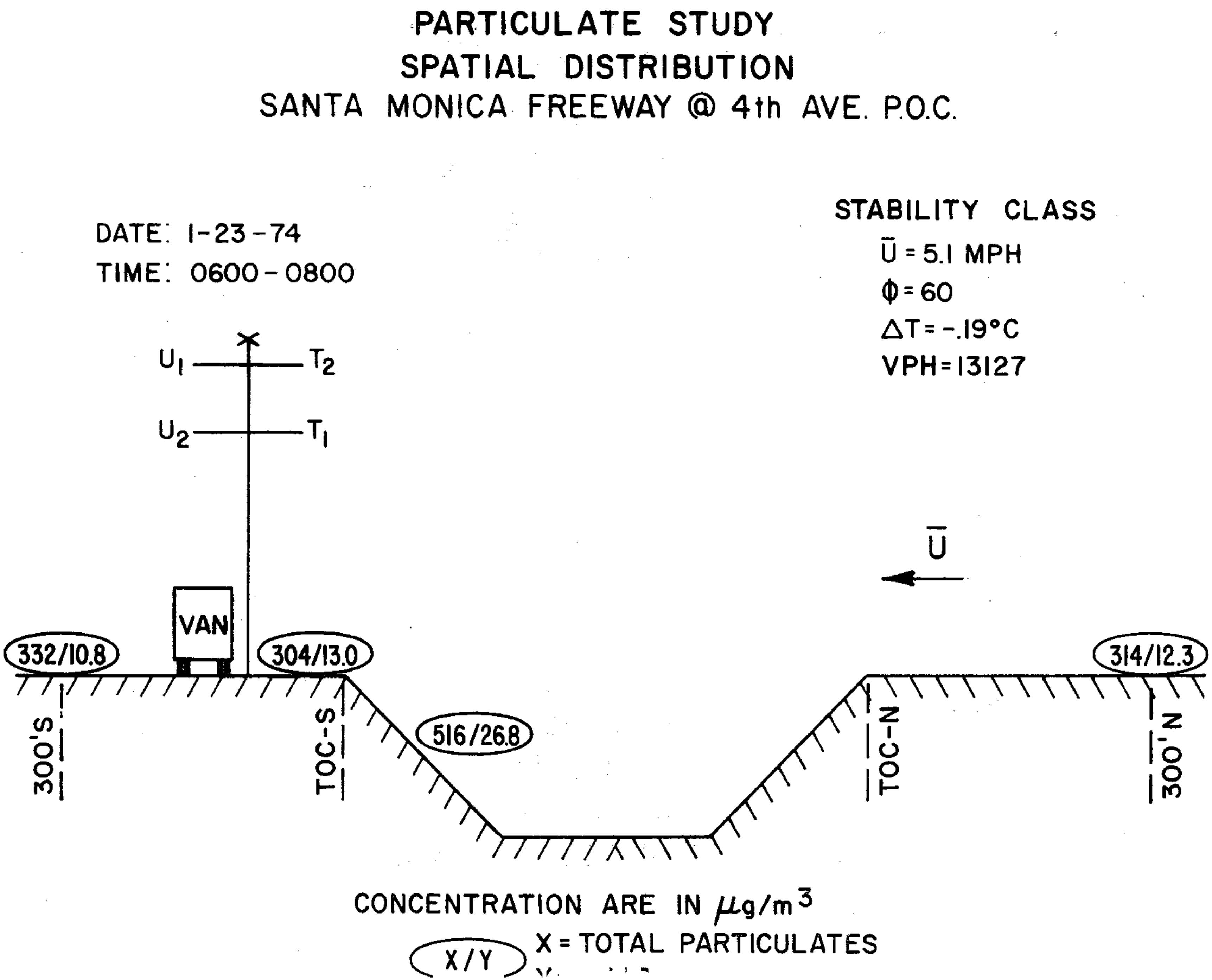
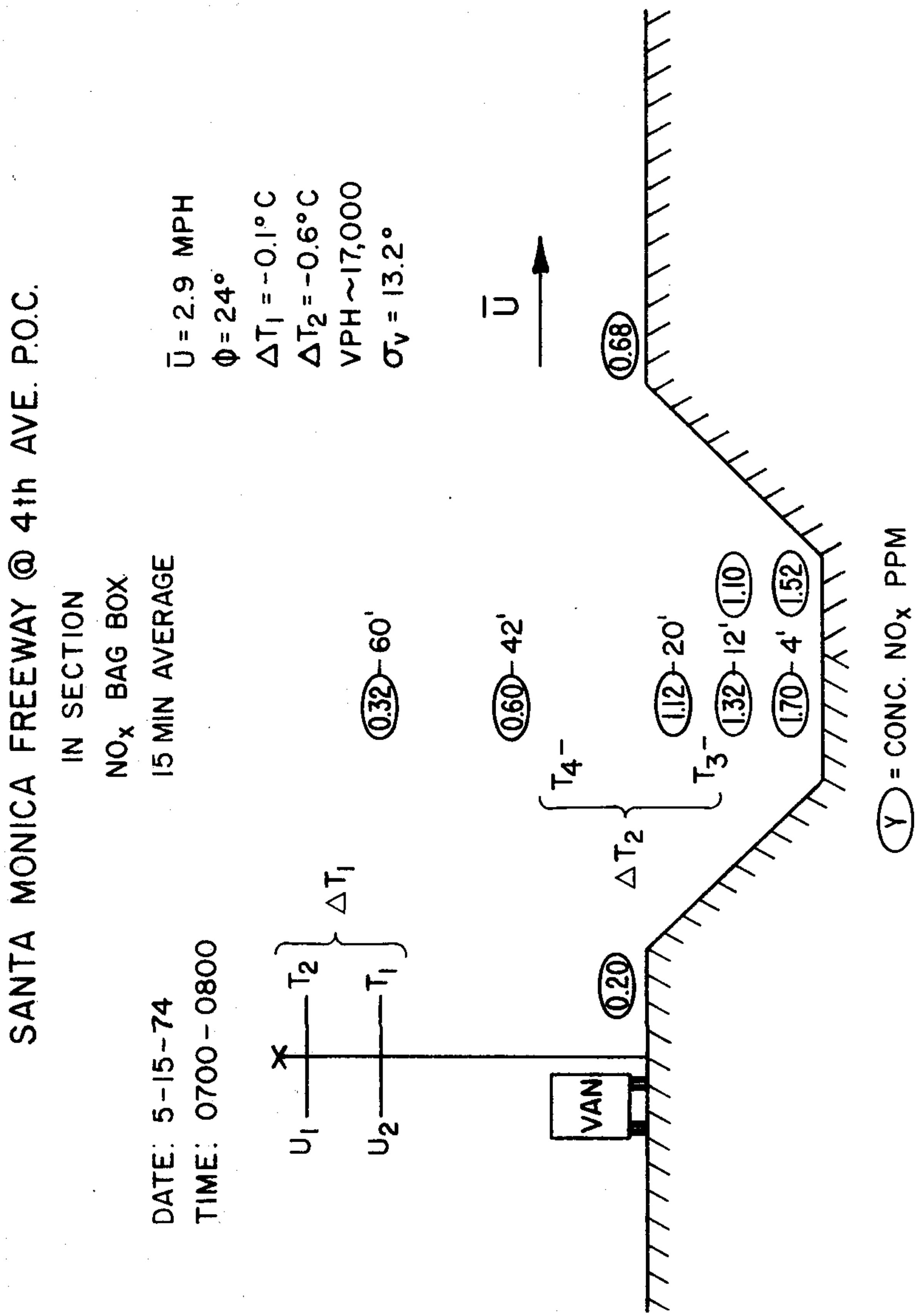

PARTICULATE STUDY
SPATIAL DISTRIBUTION
SANTA MONICA FREEWAY @ 4th AVE. P.O.C.
DATE: 1-23-74
TIME: 0600-0800
STABILITY CLASS
Ū = 5.1 MPH
Φ = 60
ΔT = -.19°C
VPH = 13127
U1
T2
U2
T1
Ū
VAN
332/10.8
304/13.0
516/26.8
314/12.3
300'S
TOC-S
TOC-N
300'N
CONCENTRATION ARE IN μg/m3
X/Y
X = TOTAL PARTICULATES

FIGURE 3C



SANTA MONICA FREEWAY @ 4th AVE. P.O.C.
IN SECTION
NOx BAG BOX
15 MIN AVERAGE
DATE: 5-15-74
TIME: 0700-0800
Ū = 2.9 MPH
φ = 24°
ΔT1 = -0.1° C
ΔT2 = -0.6° C
VPH ~ 17,000
σv = 13.2°
Ū
U1
U2
T2
T1
ΔT1
ΔT2
T4
T3
VAN
0.20
0.32
60'
0.60
42'
1.12
20'
1.10
1.32
12'
1.70
4'
1.52
0.68
Y = CONC. NOx PPM

FIGURE 12-31

SANTA MONICA FREEWAY @ 4th AVE. P.O.C.

IN SECTION

NO_2/NO-BAG BOX

15 MIN AVERAGE

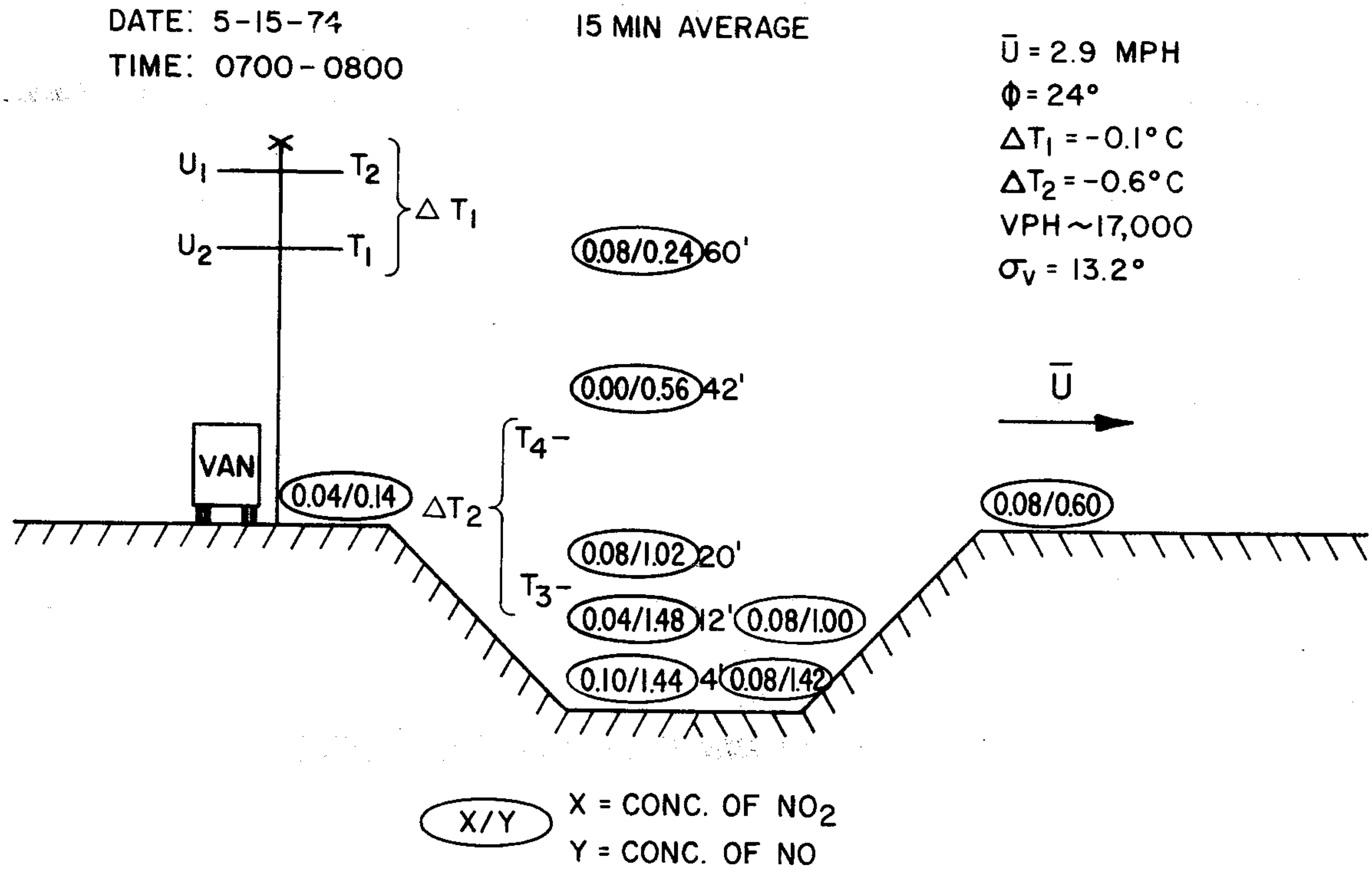


FIGURE 12-32

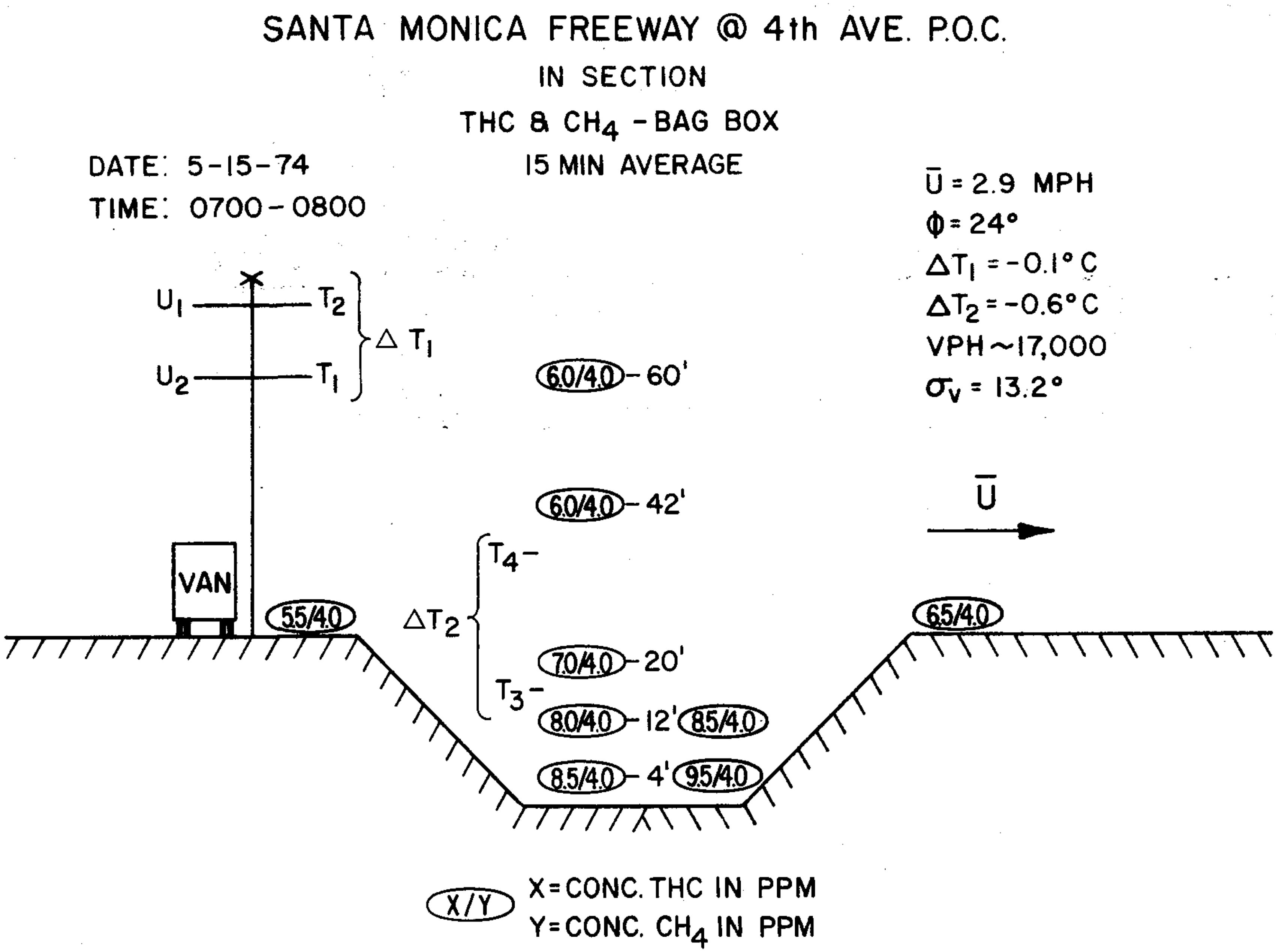

SANTA MONICA FREEWAY @ 4th AVE. P.O.C.
IN SECTION
THC & CH_4 - BAG BOX
15 MIN AVERAGE
DATE: 5-15-74
TIME: 0700-0800
$\bar{U}$ = 2.9 MPH
ϕ = 24°
ΔT_1 = -0.1° C
ΔT_2 = -0.6° C
VPH ~ 17,000
σ_v = 13.2°
U_1
U_2
T_2
T_1
ΔT_1
VAN
5.5/4.0
ΔT_2
T_4
T_3
6.0/4.0 - 60'
6.0/4.0 - 42'
7.0/4.0 - 20'
8.0/4.0 - 12' 8.5/4.0
8.5/4.0 - 4' 9.5/4.0
6.5/4.0
$\bar{U}$
X/Y
X = CONC. THC IN PPM
Y = CONC. CH_4 IN PPM

FIGURE 12-33

MODEL VALIDATION

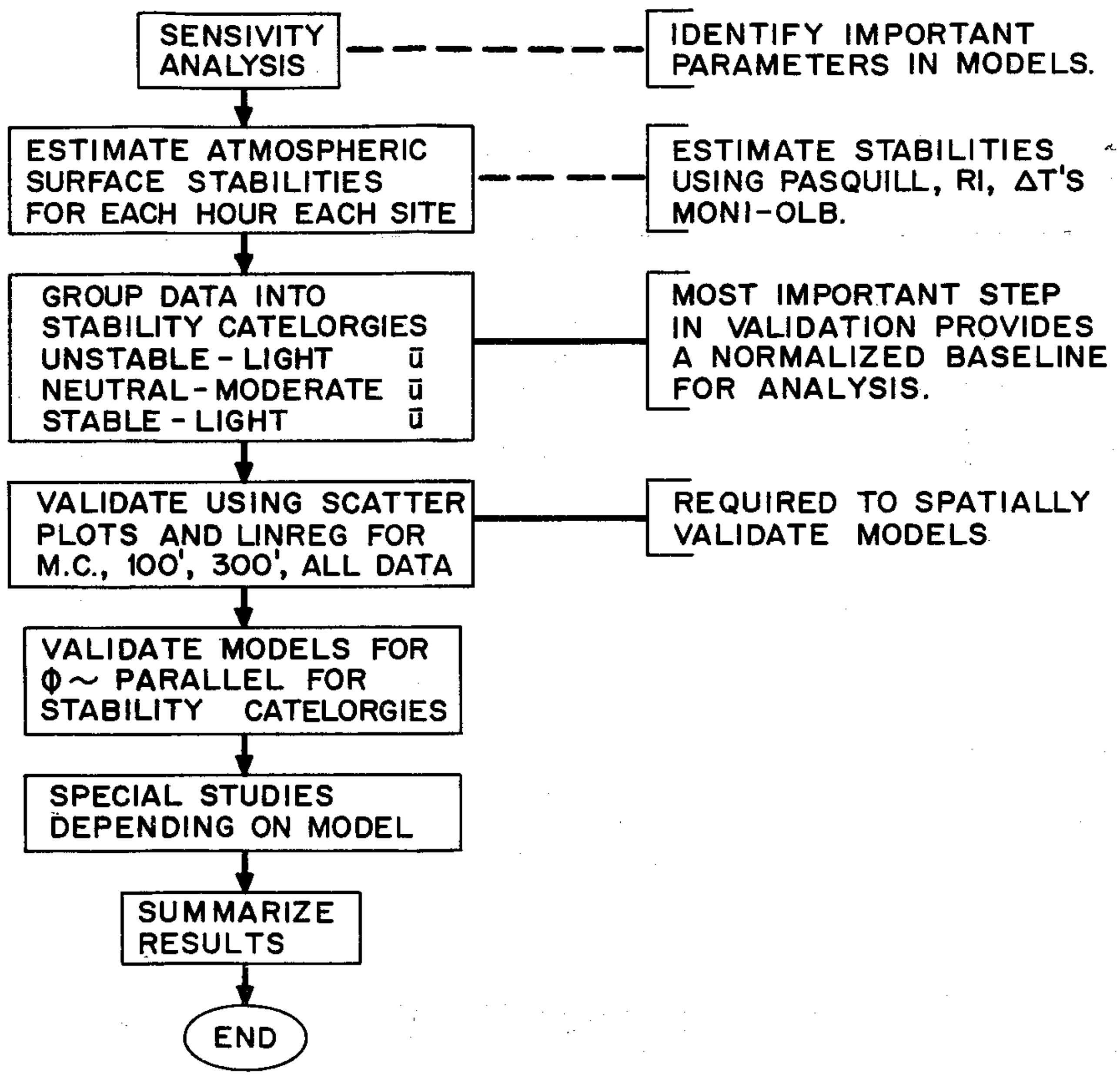


FIGURE 12-34

LOS ANGELES SAMPLING PROJECT

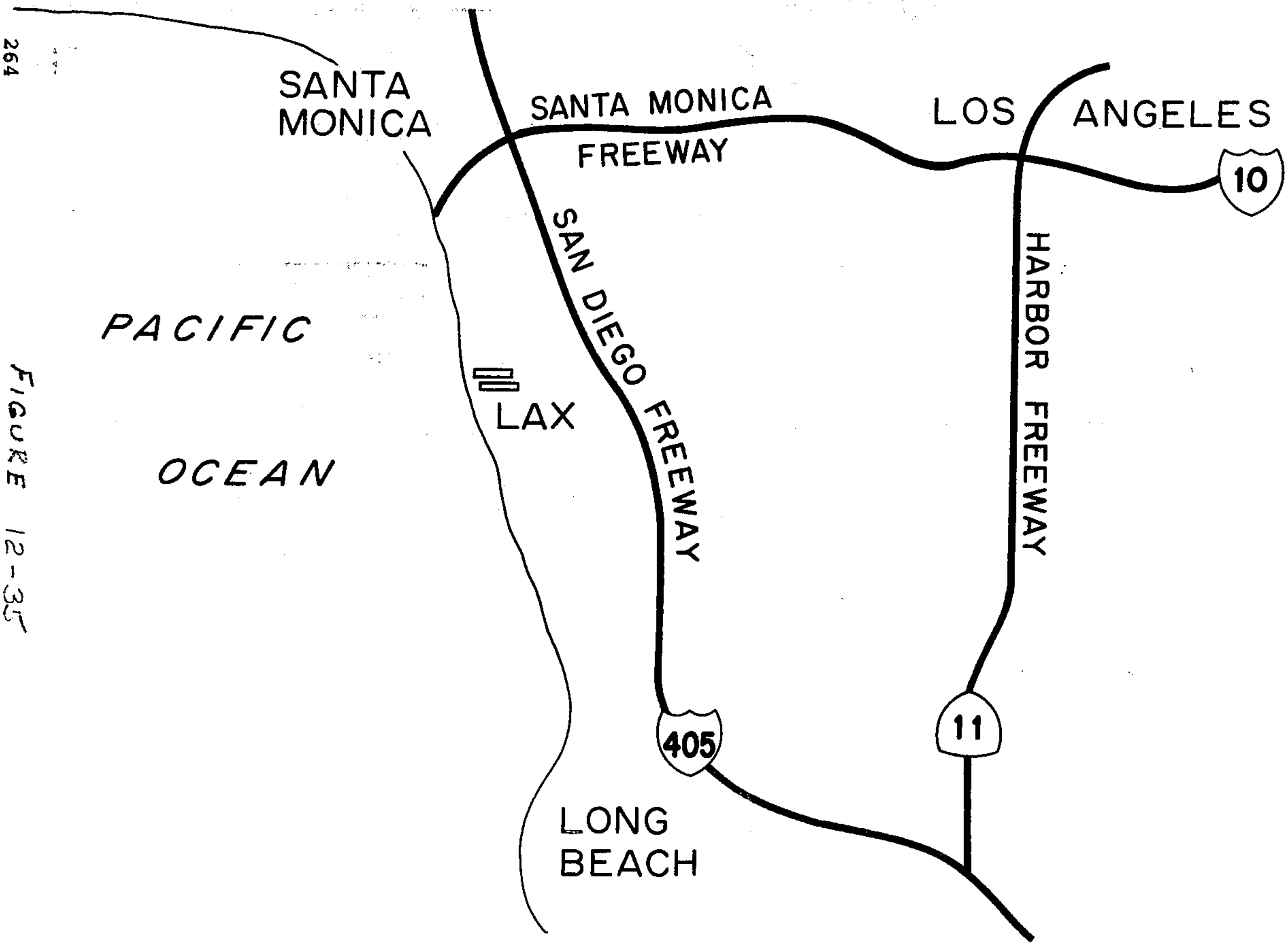
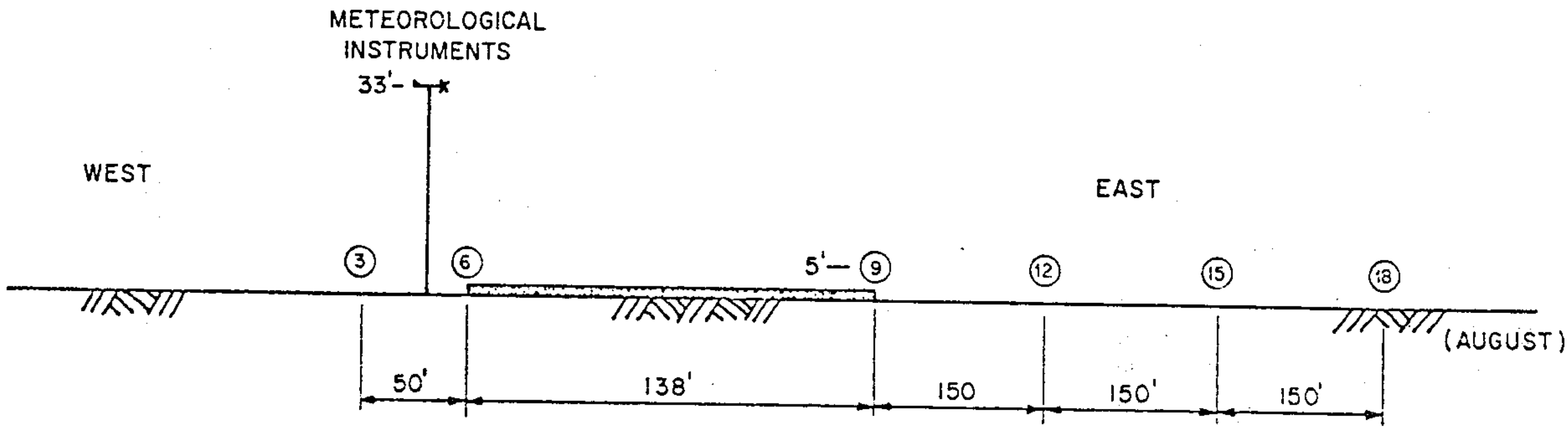


FIGURE 12-35



1 DENOTES PROBE NUMBER

PROBE LOCATION SAN DIEGO FREEWAY
AT WEIGH STATION, HORIZONTAL STUDY

Figure 12-36

AT-GRADE SITE, CROSSWIND
MIXING CELL POINTS

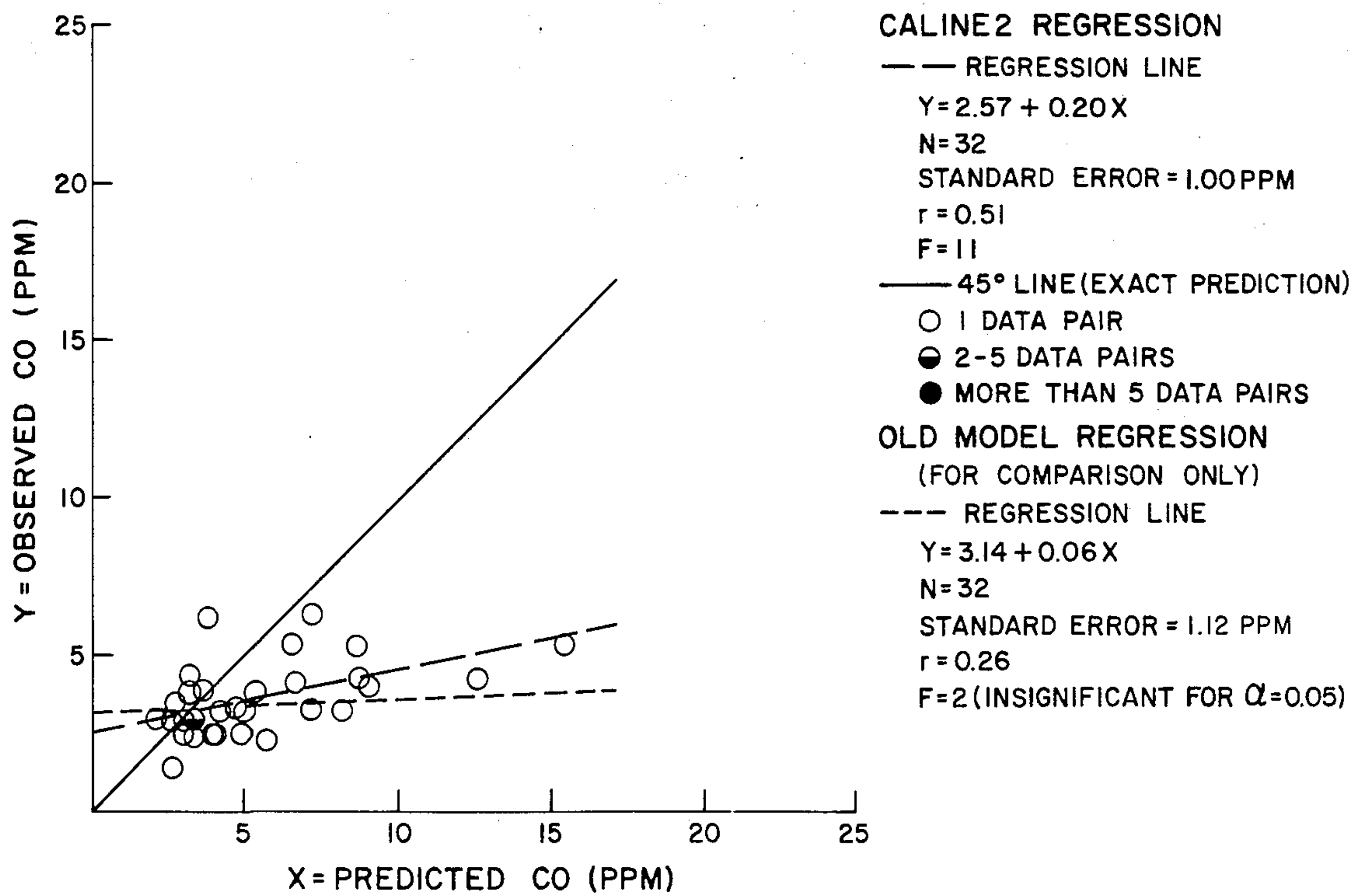


FIGURE 12-37

AT-GRADE SITE, CROSSWIND

OFF-HIGHWAY GROUND-LEVEL POINTS

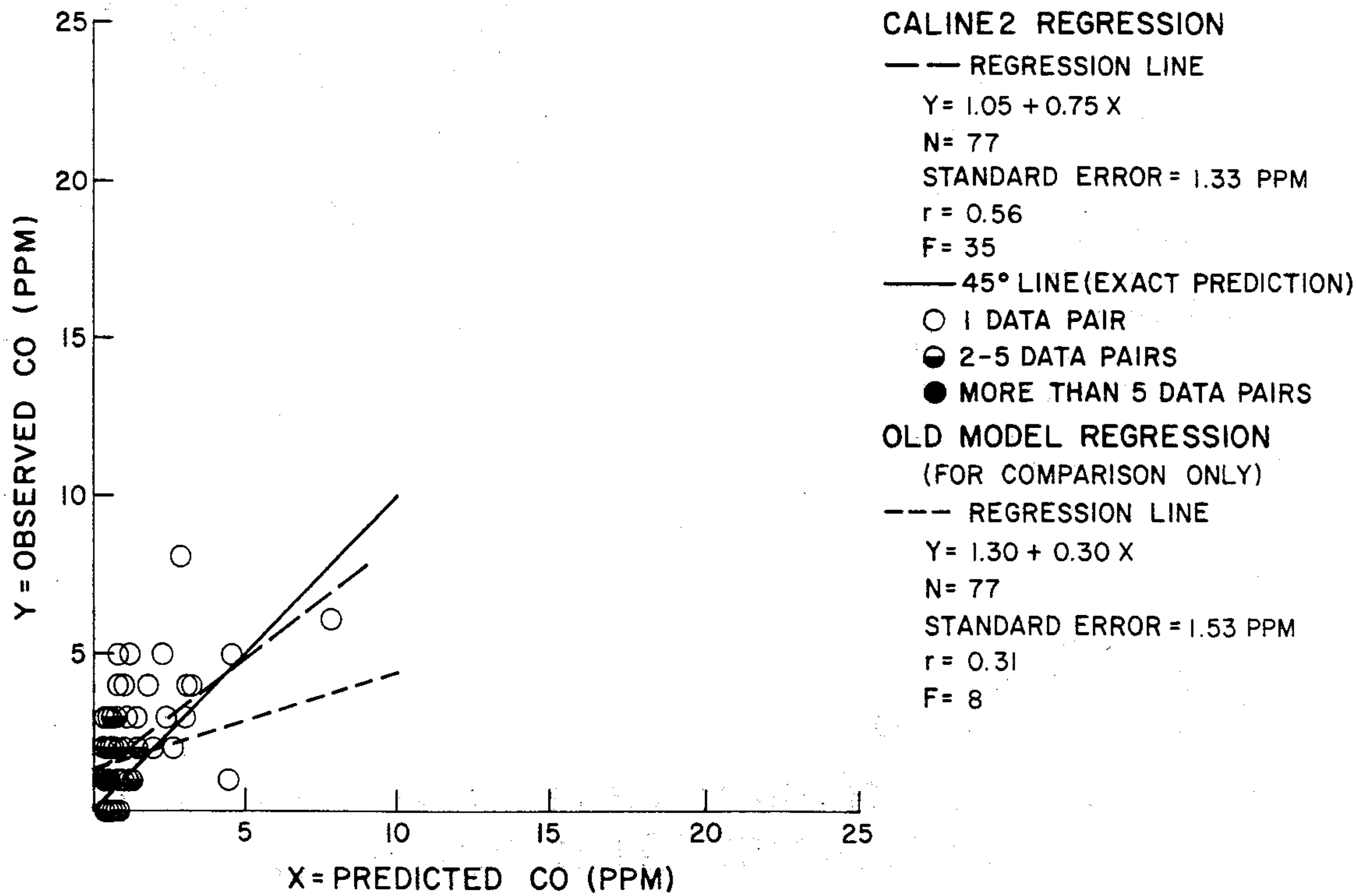


Figure 12-38

AT-GRADE SITE, CROSSWIND
OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

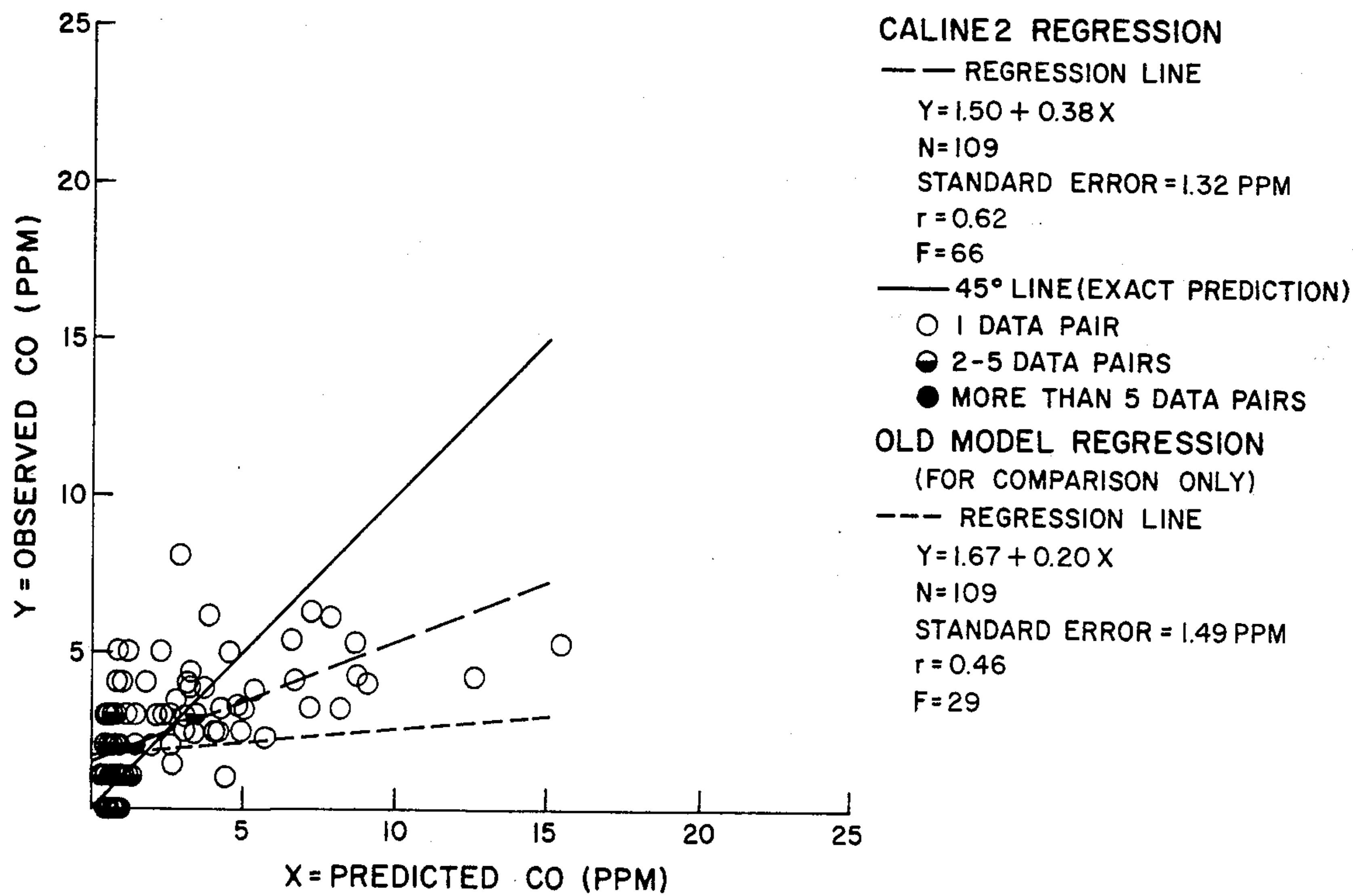


Figure 12-39

AT-GRADE SITE, PARALLEL WIND
MIXING CELL POINTS

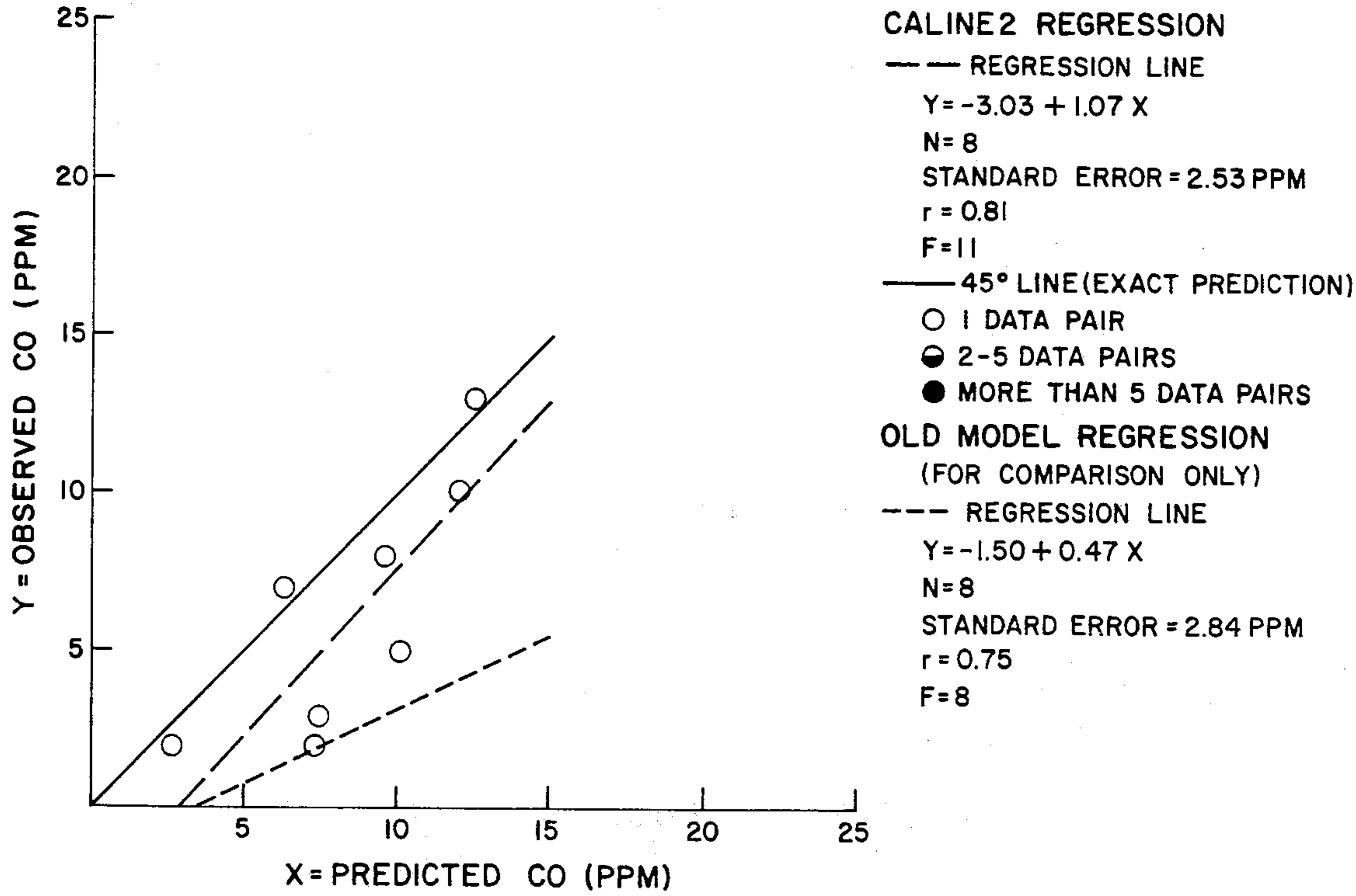


FIGURE 12-40

AT-GRADE SITE, PARALLEL WIND

OFF-HIGHWAY GROUND-LEVEL POINTS

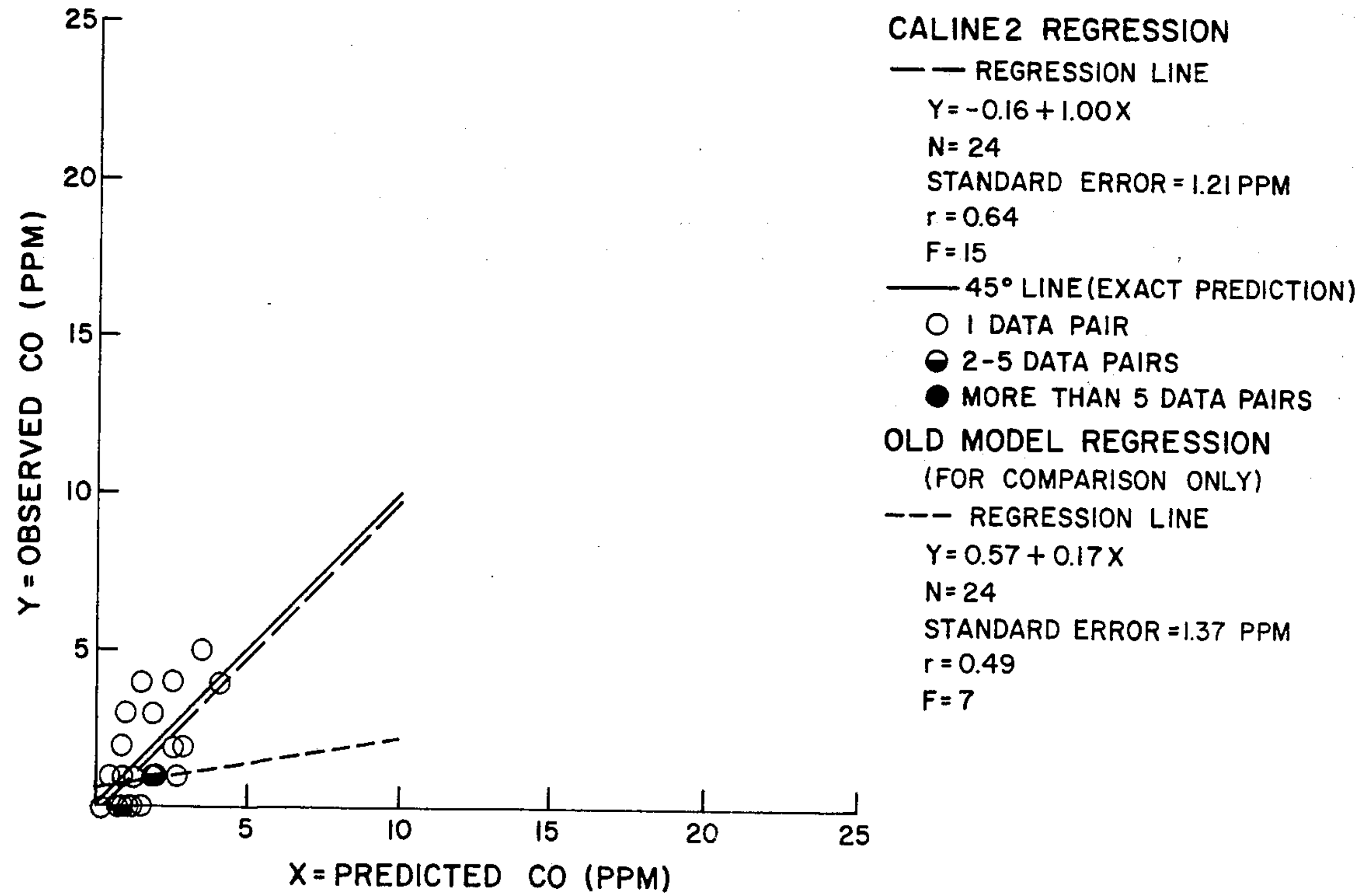


FIGURE 12-41

AT-GRADE SITE, PARALLEL WIND

OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

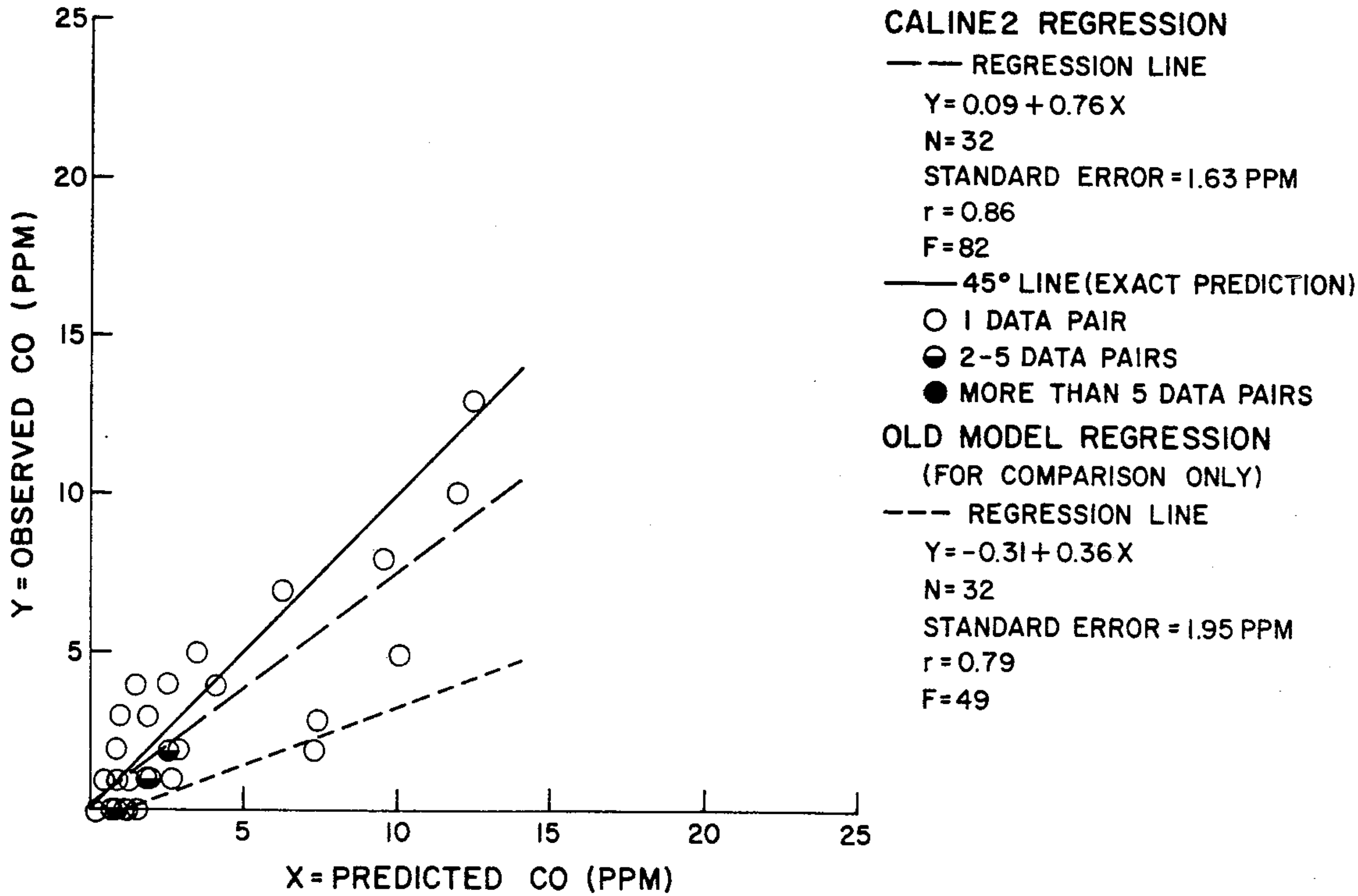
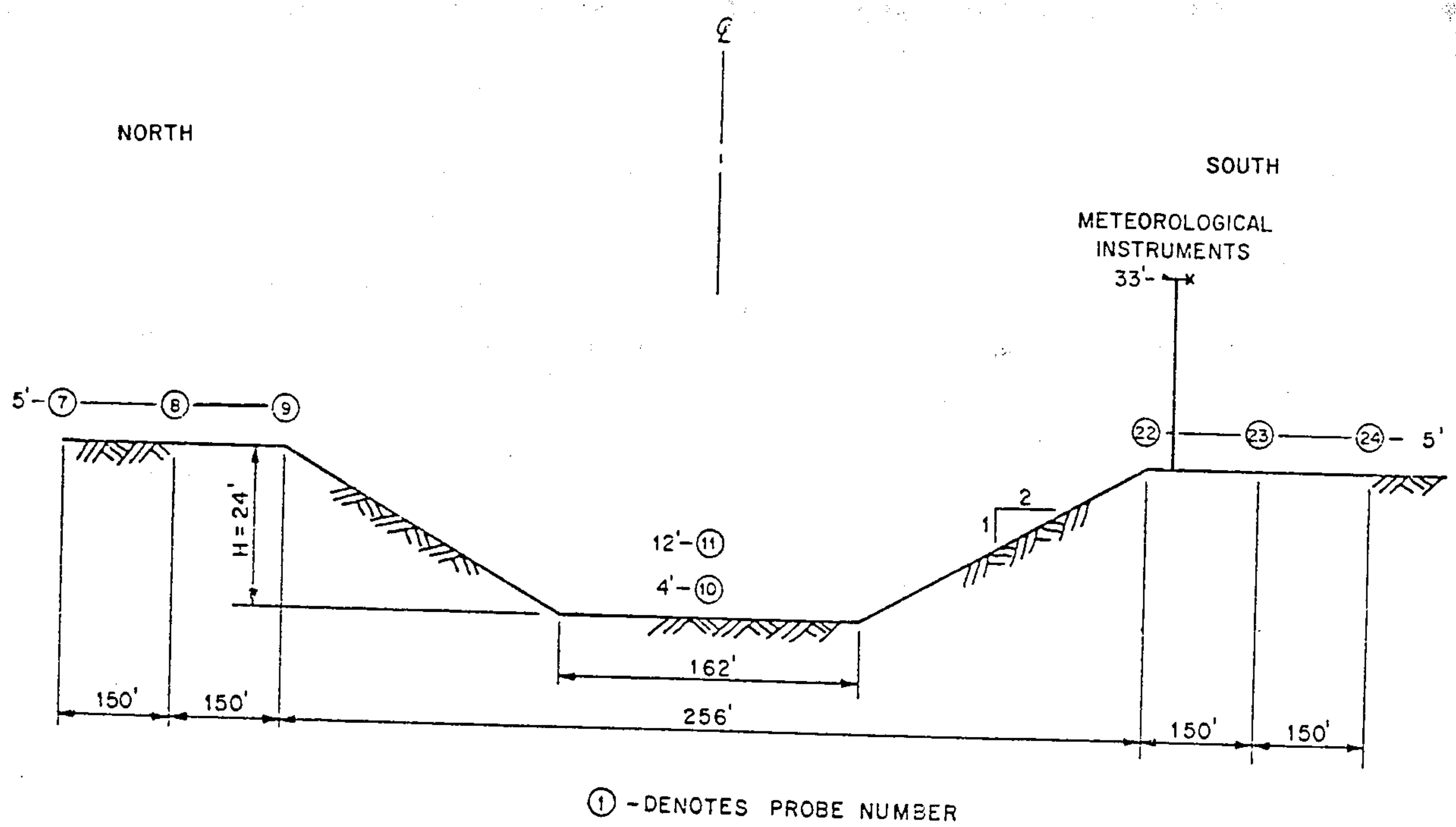
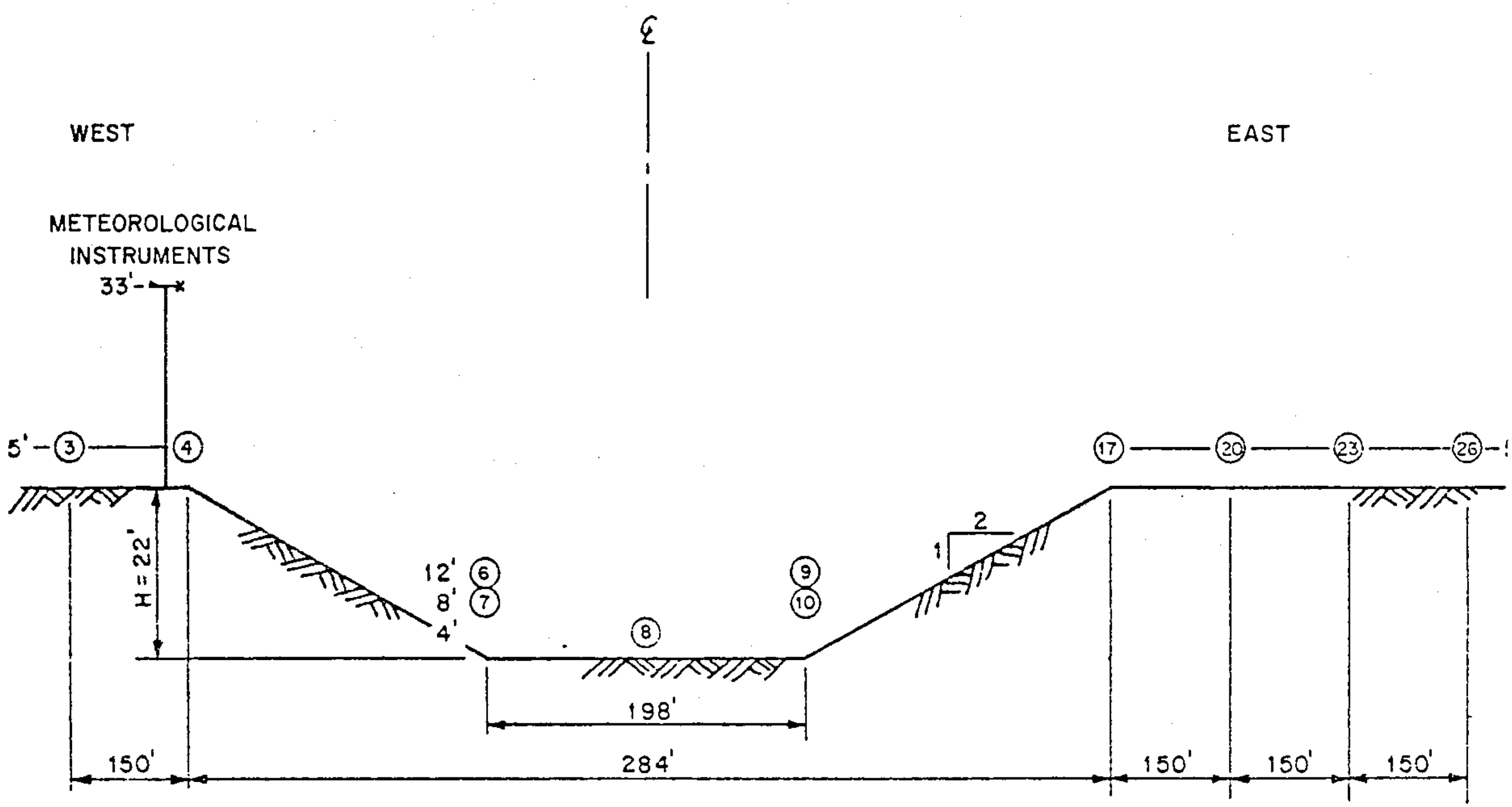


FIGURE 12-42



PROBE LOCATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. HORIZONTAL STUDY

FIGURE 12-43



① - DENOTES PROBE NUMBER

PROBE LOCATIONS, HARBOR FREEWAY
AT 146TH AVE HORIZONTAL STUDY

FIGURE 12-44

CUT SITES, CROSSWIND
MIXING CELL POINTS

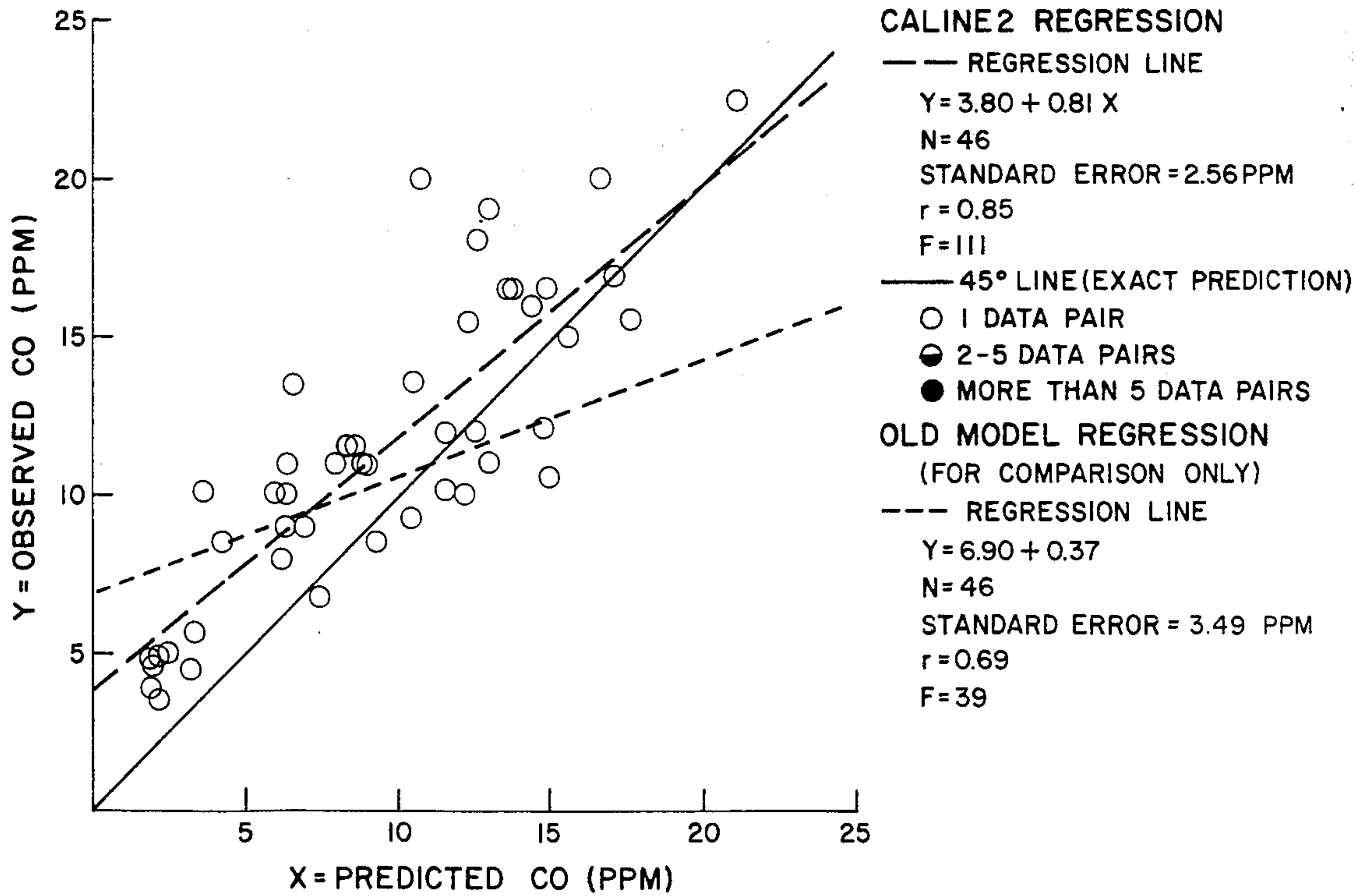


FIGURE 12-45

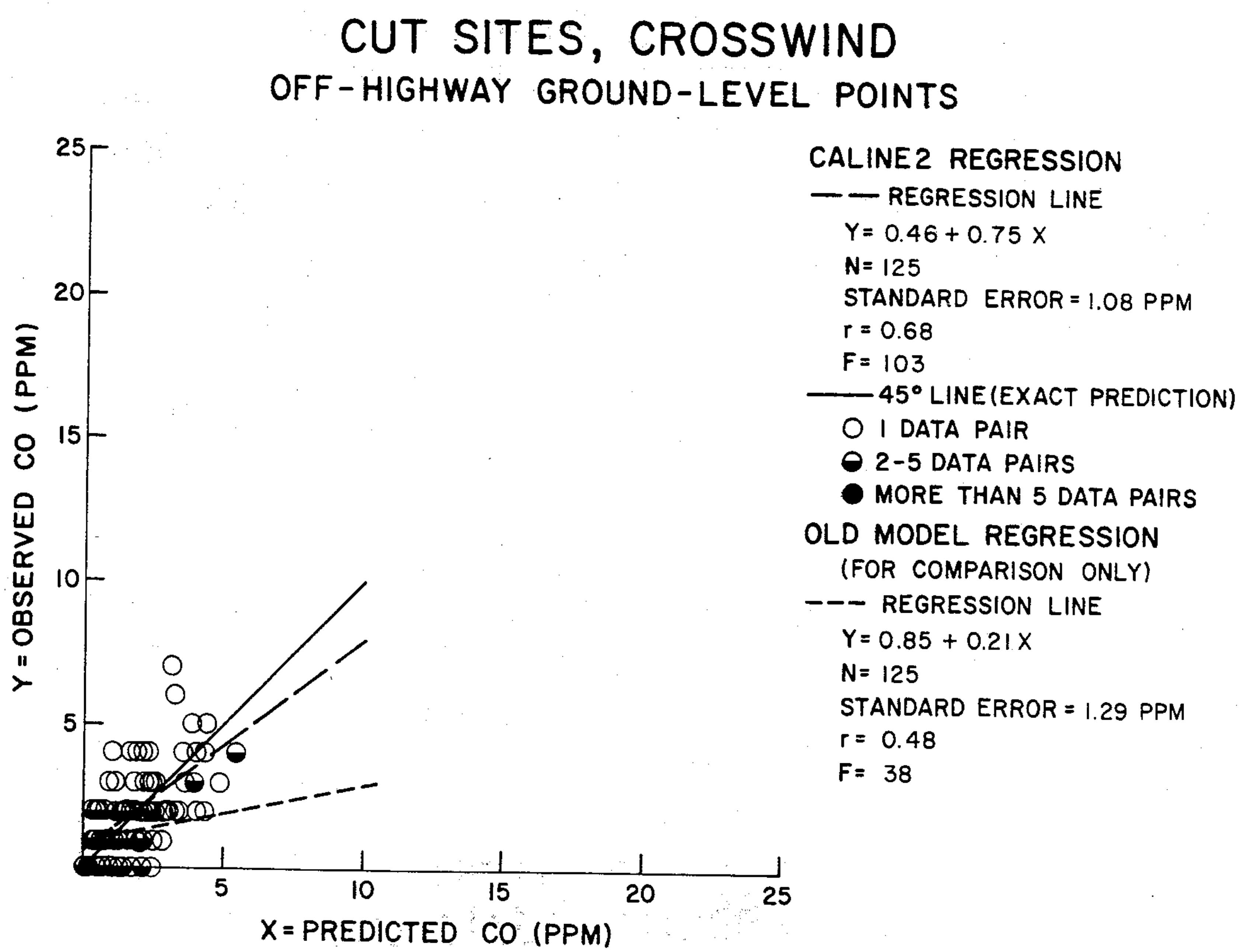

CUT SITES, CROSSWIND
OFF-HIGHWAY GROUND-LEVEL POINTS
CALINE2 REGRESSION
REGRESSION LINE
Y= 0.46 + 0.75 X
N= 125
STANDARD ERROR = 1.08 PPM
r = 0.68
F= 103
45° LINE (EXACT PREDICTION)
1 DATA PAIR
2-5 DATA PAIRS
MORE THAN 5 DATA PAIRS
OLD MODEL REGRESSION
(FOR COMPARISON ONLY)
REGRESSION LINE
Y= 0.85 + 0.21 X
N= 125
STANDARD ERROR = 1.29 PPM
r = 0.48
F= 38
Y = OBSERVED CO (PPM)
X = PREDICTED CO (PPM)
0
5
10
15
20
25

FIGURE 12-46

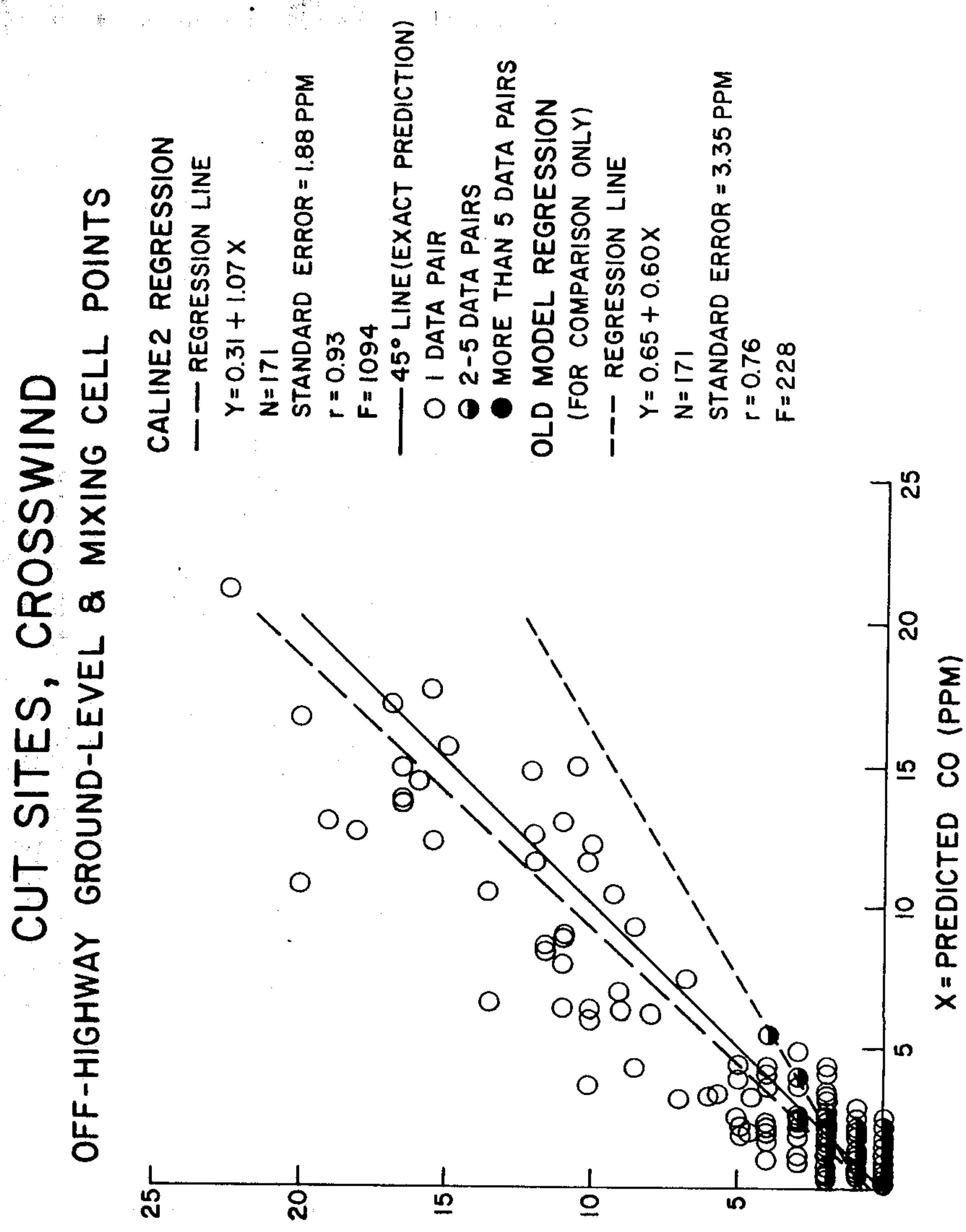

CUT SITES, CROSSWIND
OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS
CALINE2 REGRESSION
REGRESSION LINE
Y = 0.31 + 1.07 X
N = 171
STANDARD ERROR = 1.88 PPM
r = 0.93
F = 1094
45° LINE (EXACT PREDICTION)
1 DATA PAIR
2-5 DATA PAIRS
MORE THAN 5 DATA PAIRS
OLD MODEL REGRESSION
(FOR COMPARISON ONLY)
REGRESSION LINE
Y = 0.65 + 0.60 X
N = 171
STANDARD ERROR = 3.35 PPM
r = 0.76
F = 228
Y = OBSERVED CO (PPM)
X = PREDICTED CO (PPM)
0
5
10
15
20
25

FIGURE 12-47

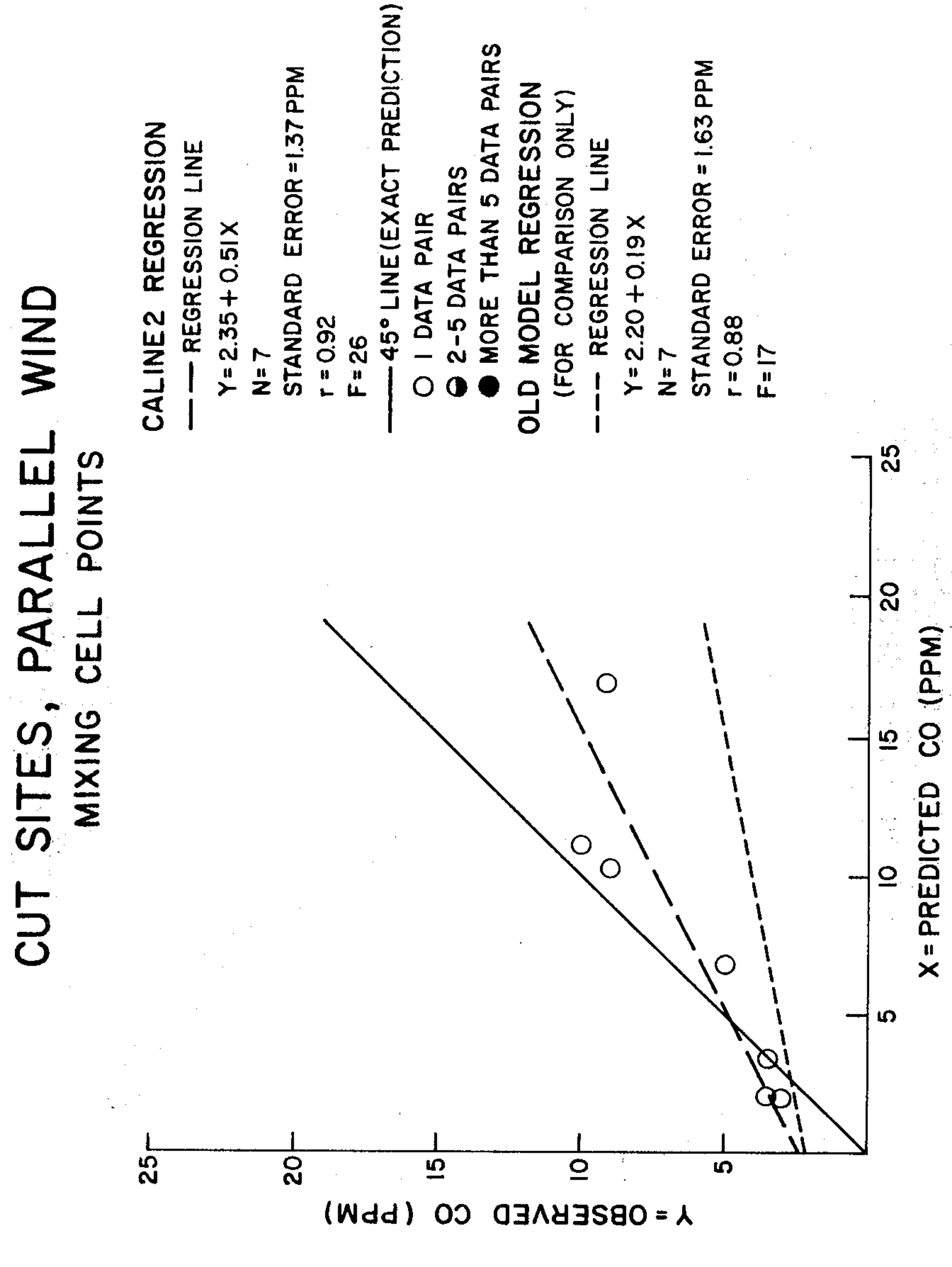

CUT SITES, PARALLEL WIND
MIXING CELL POINTS
CALINE2 REGRESSION
REGRESSION LINE
Y = 2.35 + 0.51X
N = 7
STANDARD ERROR = 1.37 PPM
r = 0.92
F = 26
45° LINE (EXACT PREDICTION)
1 DATA PAIR
2-5 DATA PAIRS
MORE THAN 5 DATA PAIRS
OLD MODEL REGRESSION
(FOR COMPARISON ONLY)
REGRESSION LINE
Y = 2.20 + 0.19 X
N = 7
STANDARD ERROR = 1.63 PPM
r = 0.88
F = 17
Y = OBSERVED CO (PPM)
X = PREDICTED CO (PPM)
5
10
15
20
25

FIGURE 12-48

CUT SITES, PARALLEL WIND

OFF-HIGHWAY GROUND-LEVEL POINTS

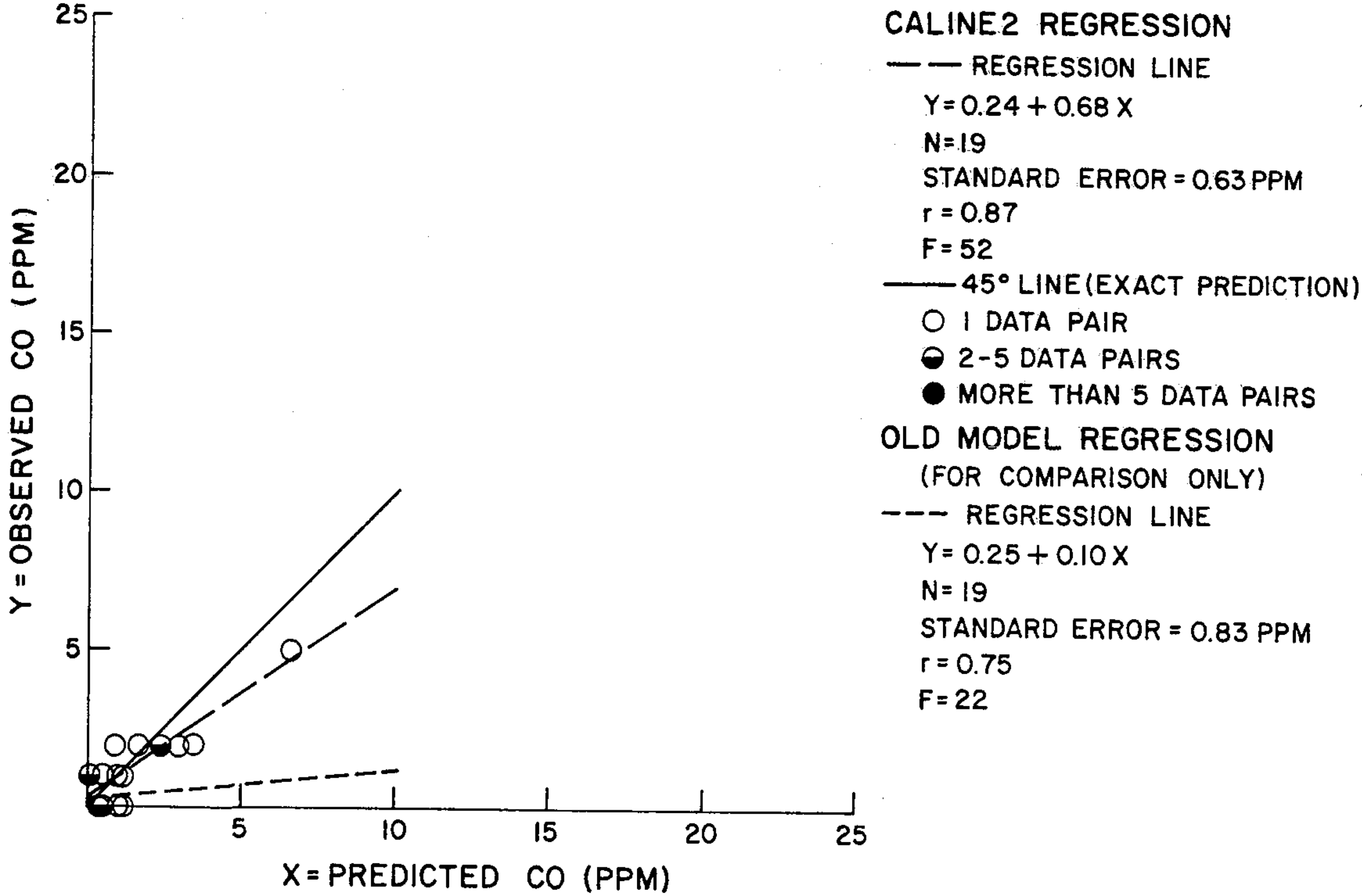


Figure 12-49

CUT SITES, PARALLEL WIND
OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

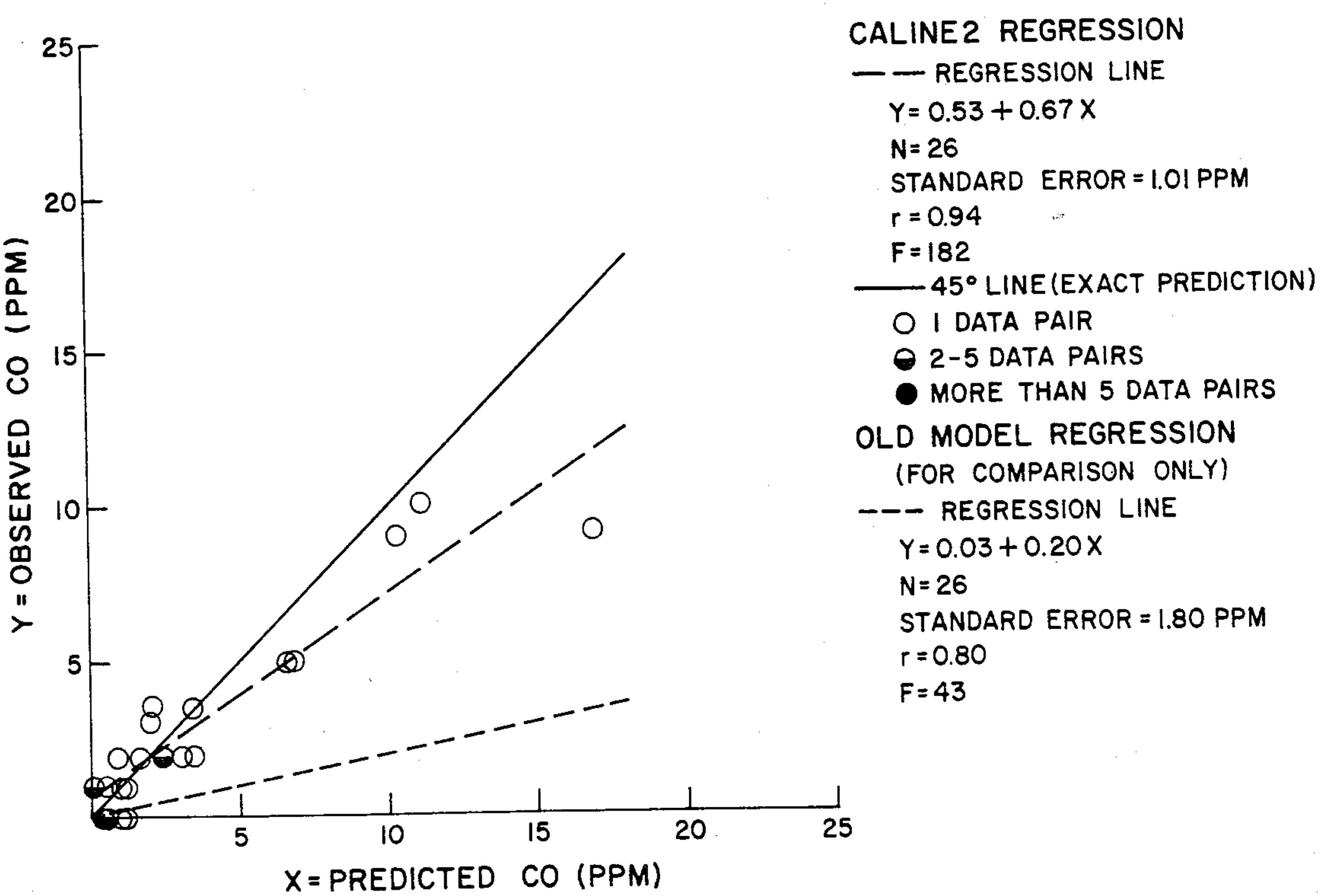
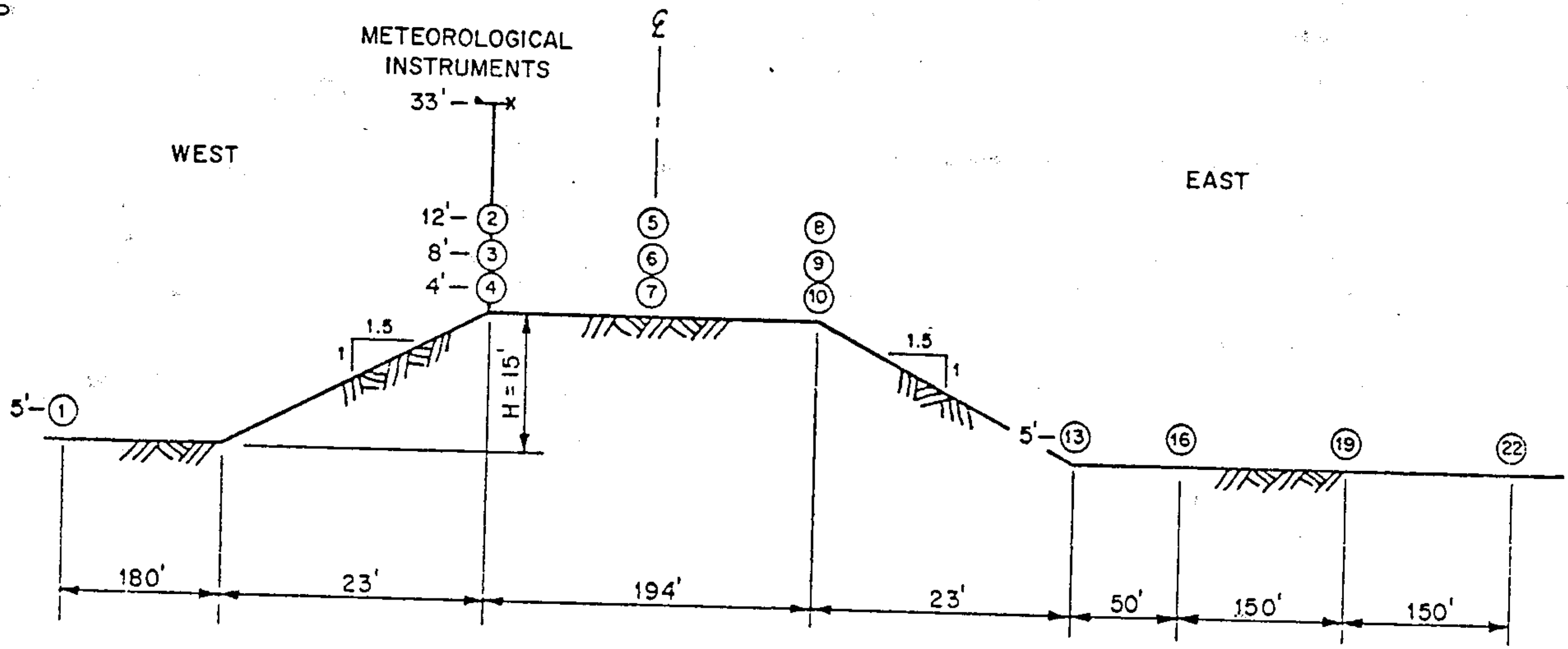


FIGURE 12-50



1 — DENOTES PROBE NUMBER

PROBE LOCATIONS SAN DIEGO FREEWAY
AT 122ND AVE HORIZONTAL STUDY

Figure 12.51

FILL SITE, CROSSWIND
MIXING CELL POINTS

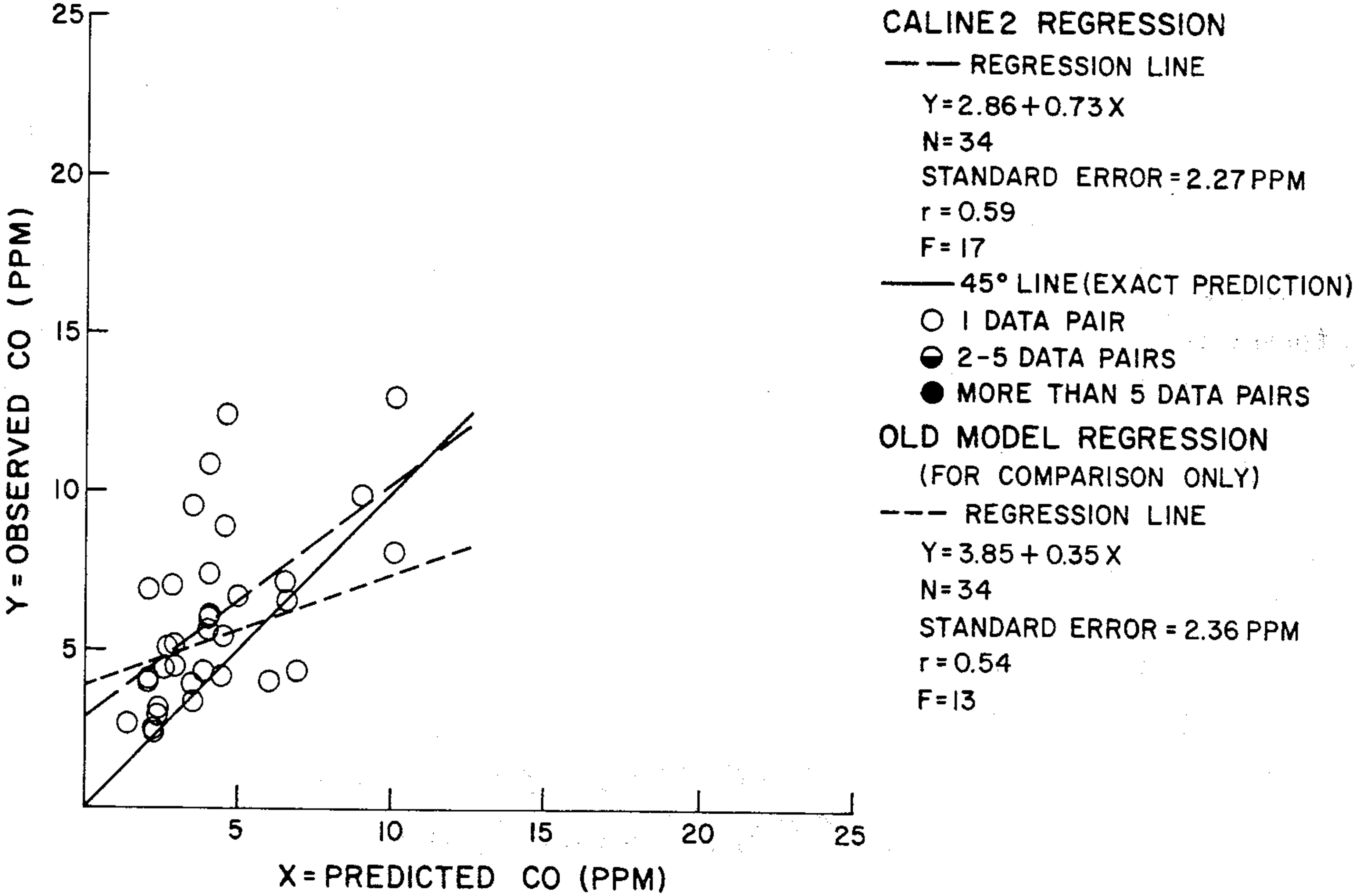


FIGURE 12-52

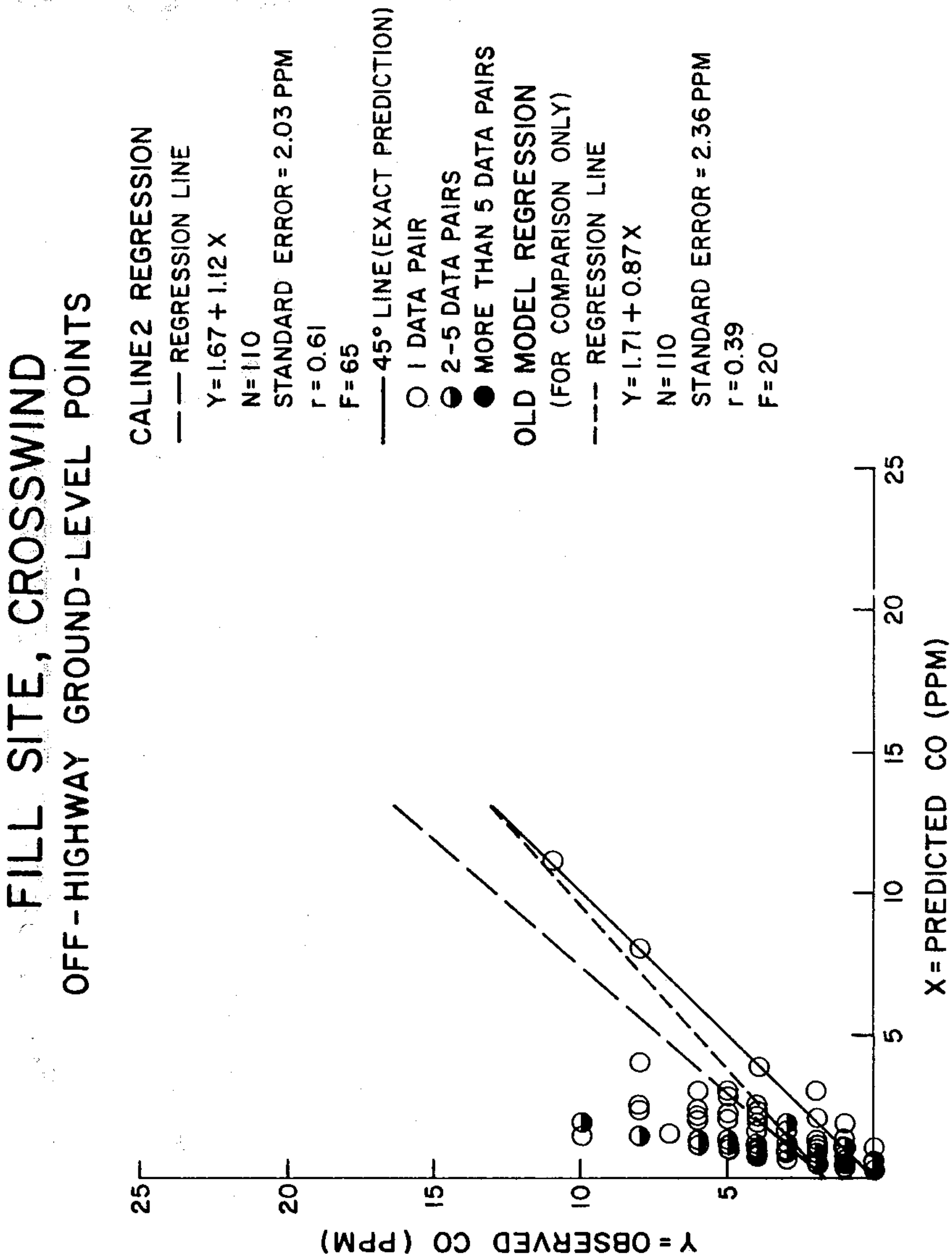

FILL SITE, CROSSWIND
OFF-HIGHWAY GROUND-LEVEL POINTS
CALINE2 REGRESSION
REGRESSION LINE
Y = 1.67 + 1.12 X
N = 110
STANDARD ERROR = 2.03 PPM
r = 0.61
F = 65
45° LINE (EXACT PREDICTION)
1 DATA PAIR
2-5 DATA PAIRS
MORE THAN 5 DATA PAIRS
OLD MODEL REGRESSION
(FOR COMPARISON ONLY)
REGRESSION LINE
Y = 1.71 + 0.87 X
N = 110
STANDARD ERROR = 2.36 PPM
r = 0.39
F = 20
Y = OBSERVED CO (PPM)
X = PREDICTED CO (PPM)
0
5
10
15
20
25

FIGURE 12-53

FILL SITE, CROSSWIND

OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

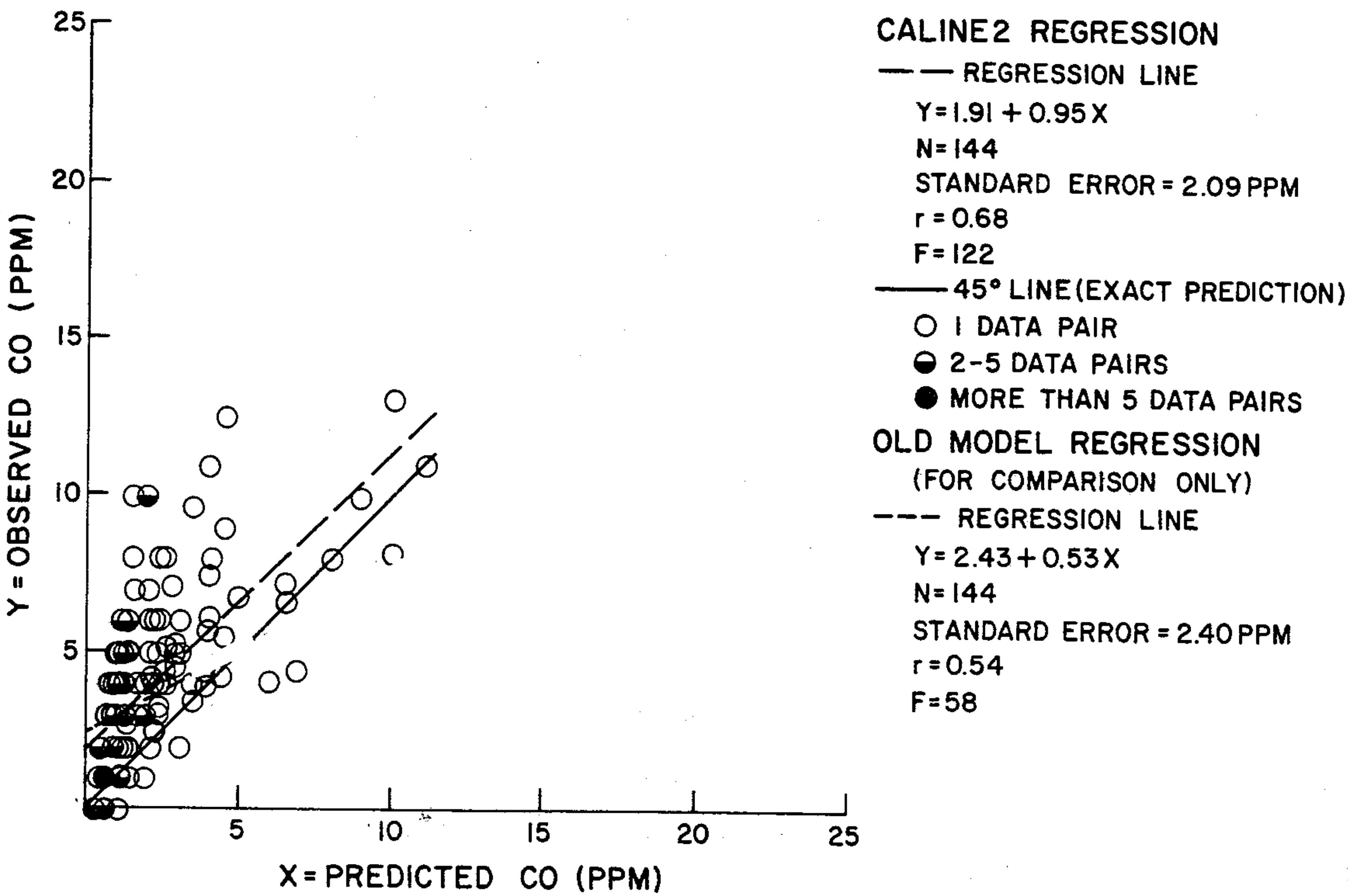
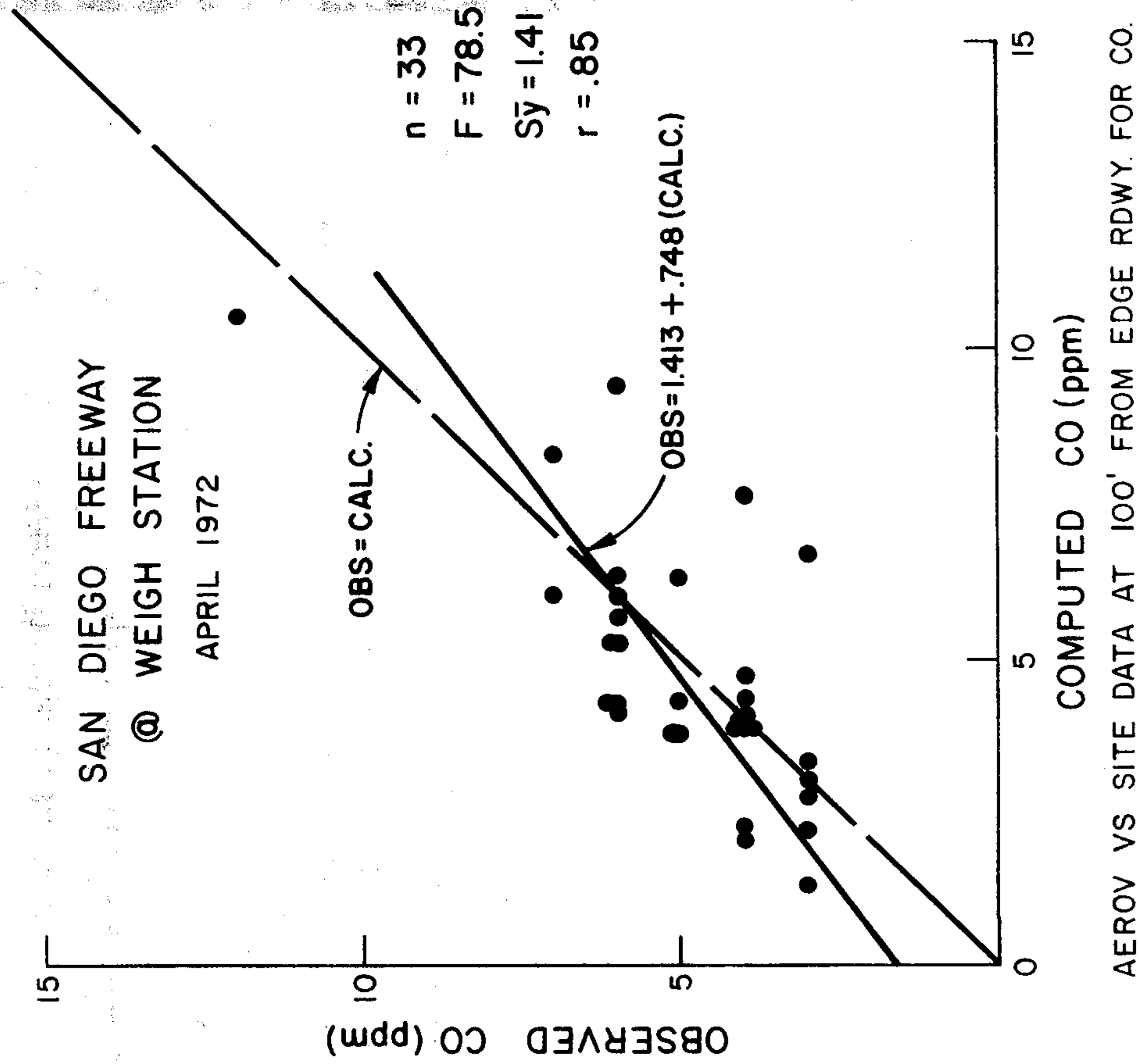


FIGURE 12-54



SAN DIEGO FREEWAY
@ WEIGH STATION
APRIL 1972
n = 33
F = 78.5
Sȳ = 1.41
r = .85
OBS = CALC.
OBS = 1.413 + .748 (CALC.)
OBSERVED CO (ppm)
COMPUTED CO (ppm)
AEROV VS SITE DATA AT 100' FROM EDGE RDWY. FOR CO.
0
5
10
15

FIGURE 12-55

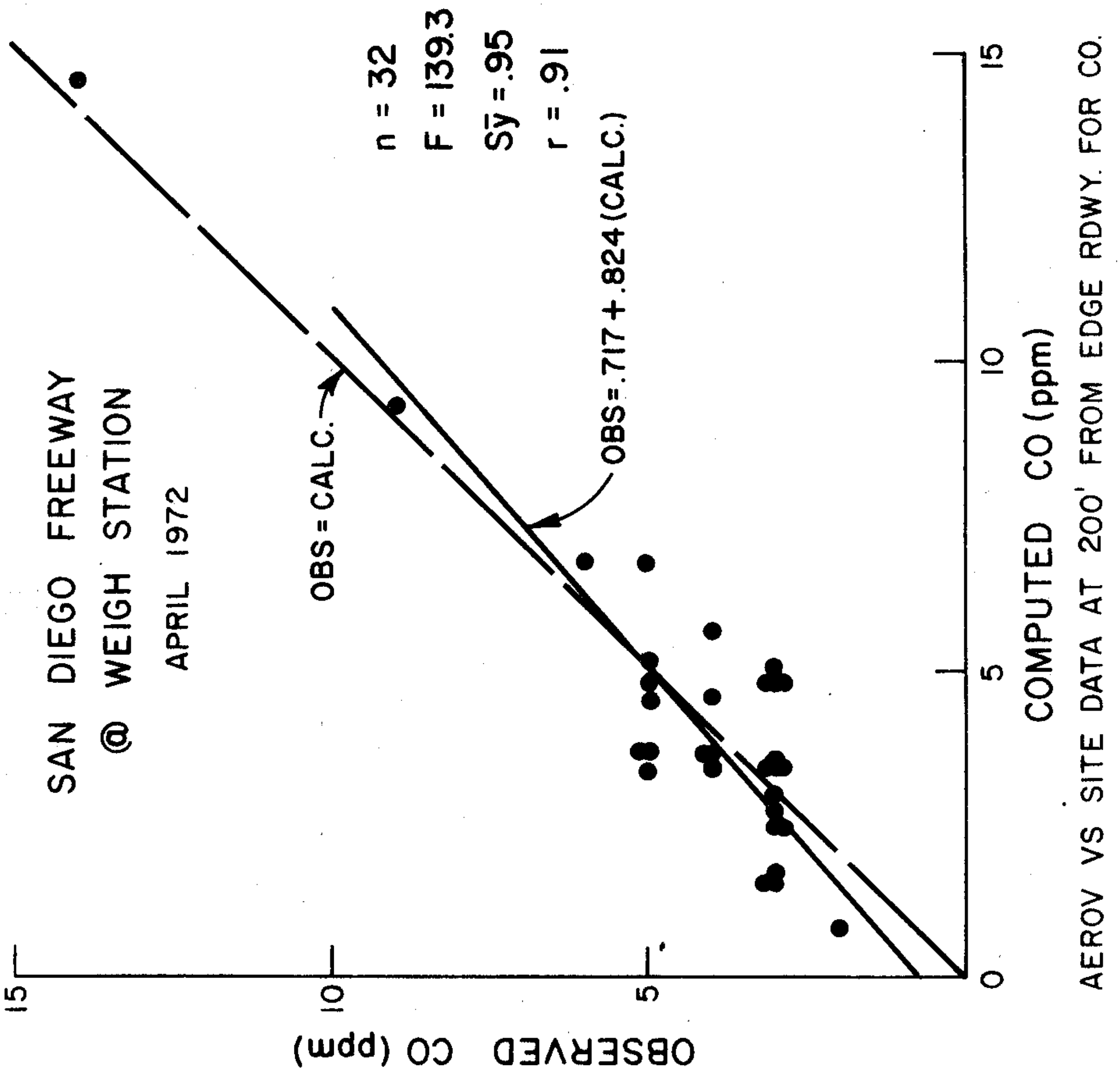
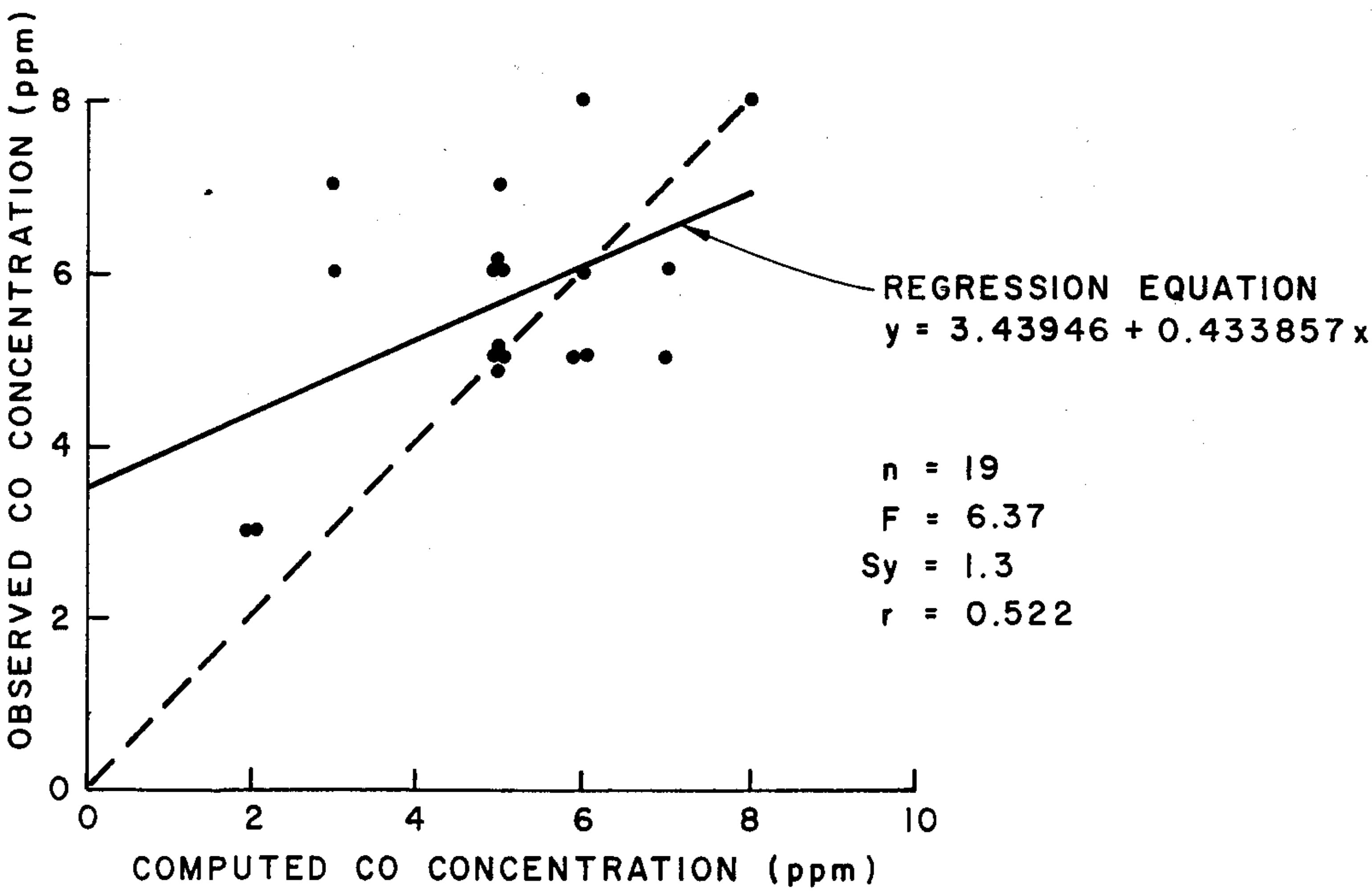

SAN DIEGO FREEWAY
@ WEIGH STATION
APRIL 1972
n = 32
F = 139.3
$S_{\bar{y}}$ = .95
r = .91
OBS = CALC.
OBS = .717 + .824 (CALC.)
OBSERVED CO (ppm)
COMPUTED CO (ppm)
AEROV VS SITE DATA AT 200' FROM EDGE RDWY. FOR CO.
0
5
10
15

FIGURE 12-56

AERO VIRONMENT LINE SOURCE MODEL
VS SITE DATA AT 150 FT FROM ROADWAY
AUGUST 1972



AERO VIRONMENT LINE SOURCE MODEL
VS SITE DATA AT 300 FT FROM ROADWAY
AUGUST 1972

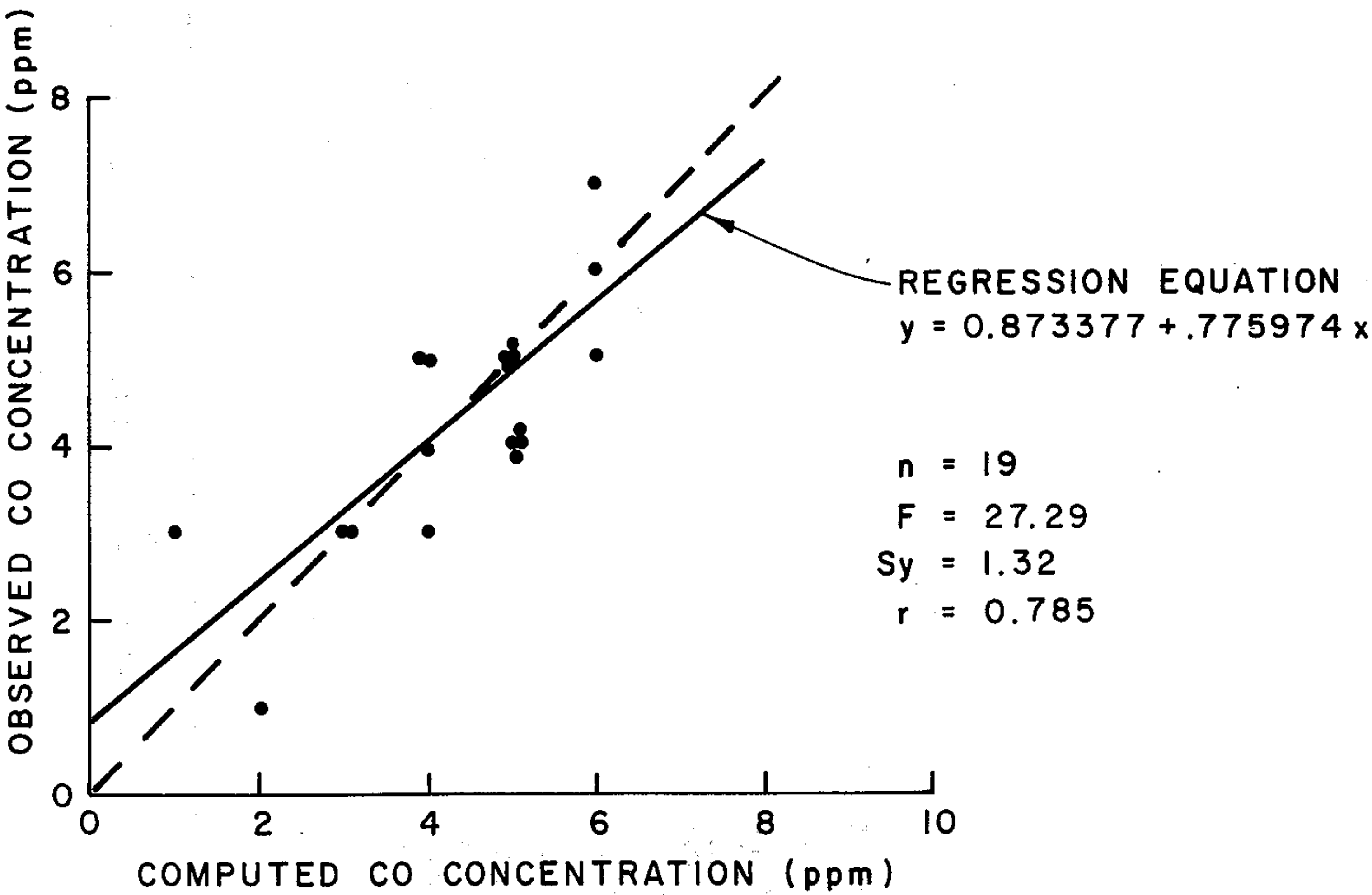
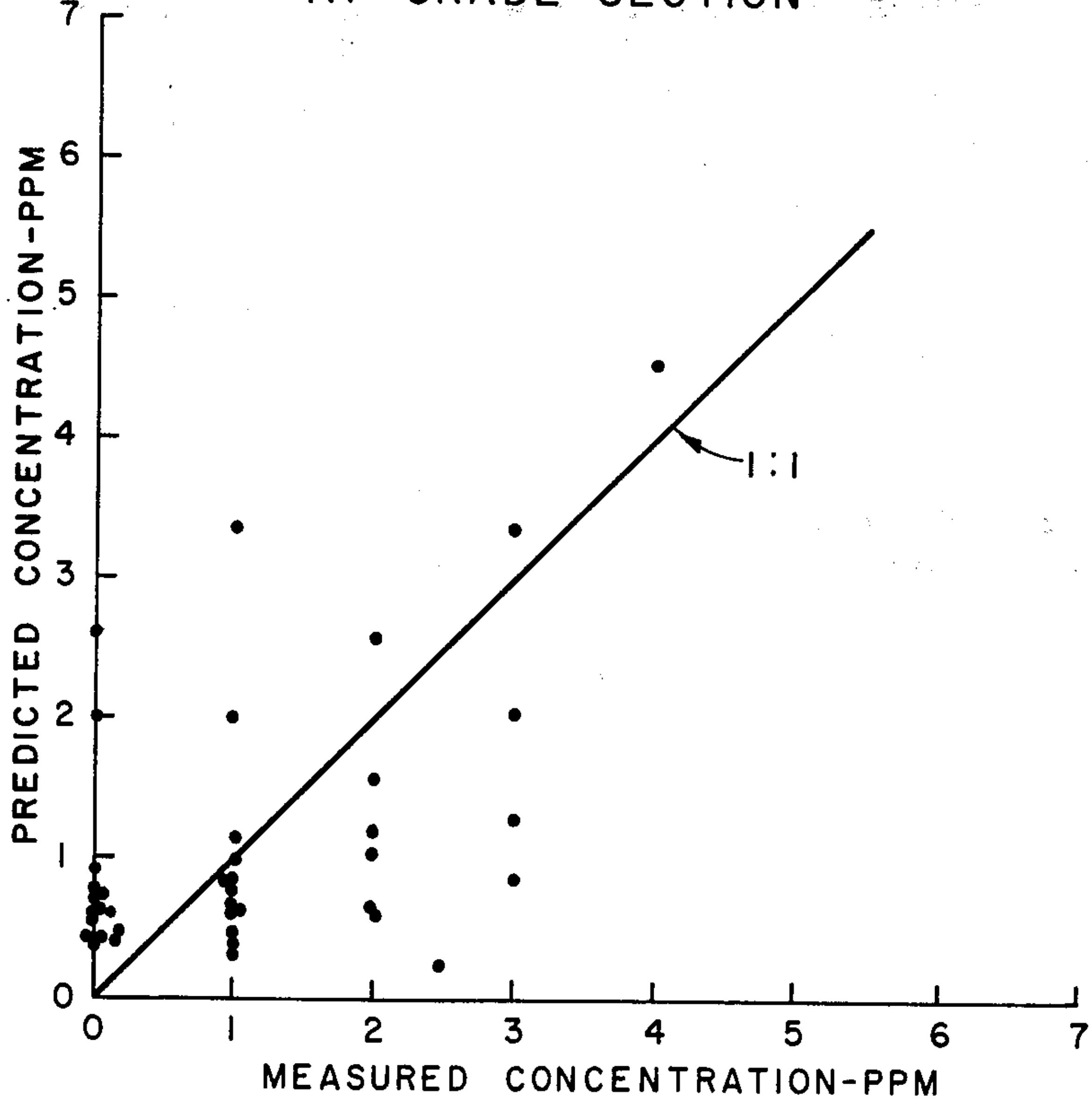


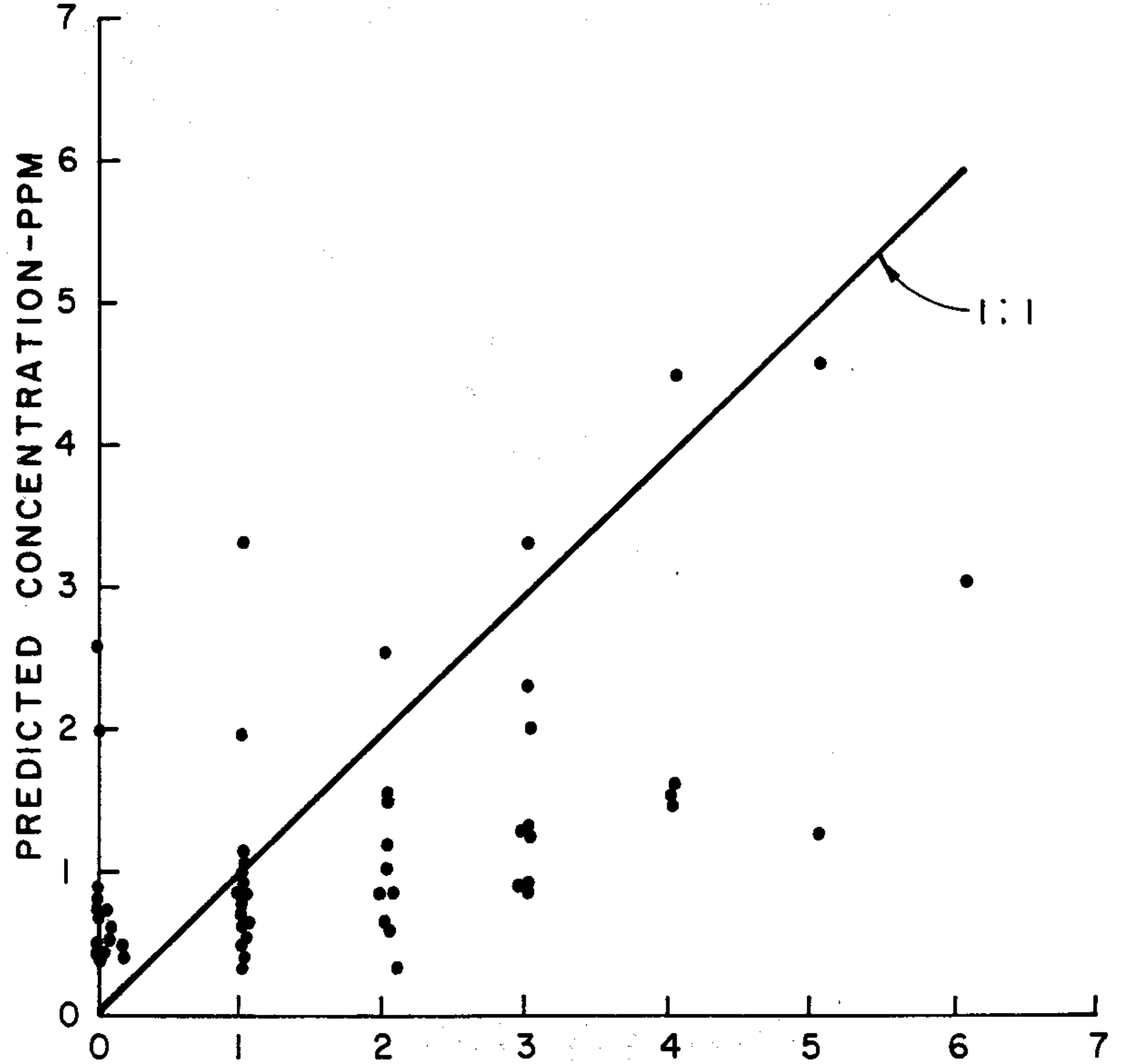
FIGURE 12-58

OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS—
AT-GRADE SECTION



SOURCE: S^3 REPORT

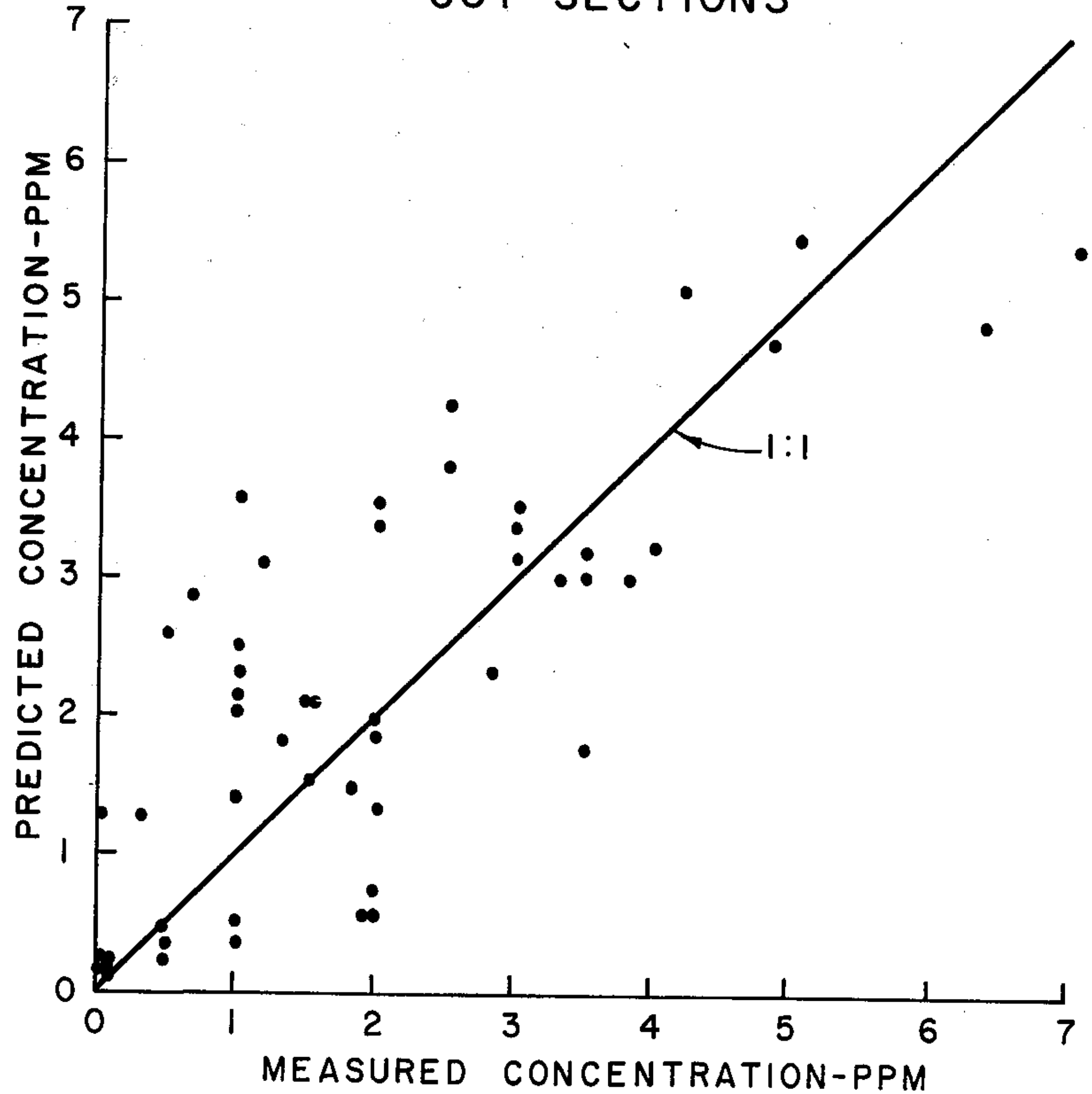
OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS—
(INCLUDING ROAD EDGE PTS.) AT-GRADE SECTION



SOURCE: S^3 REPORT

FIGURE 12-60

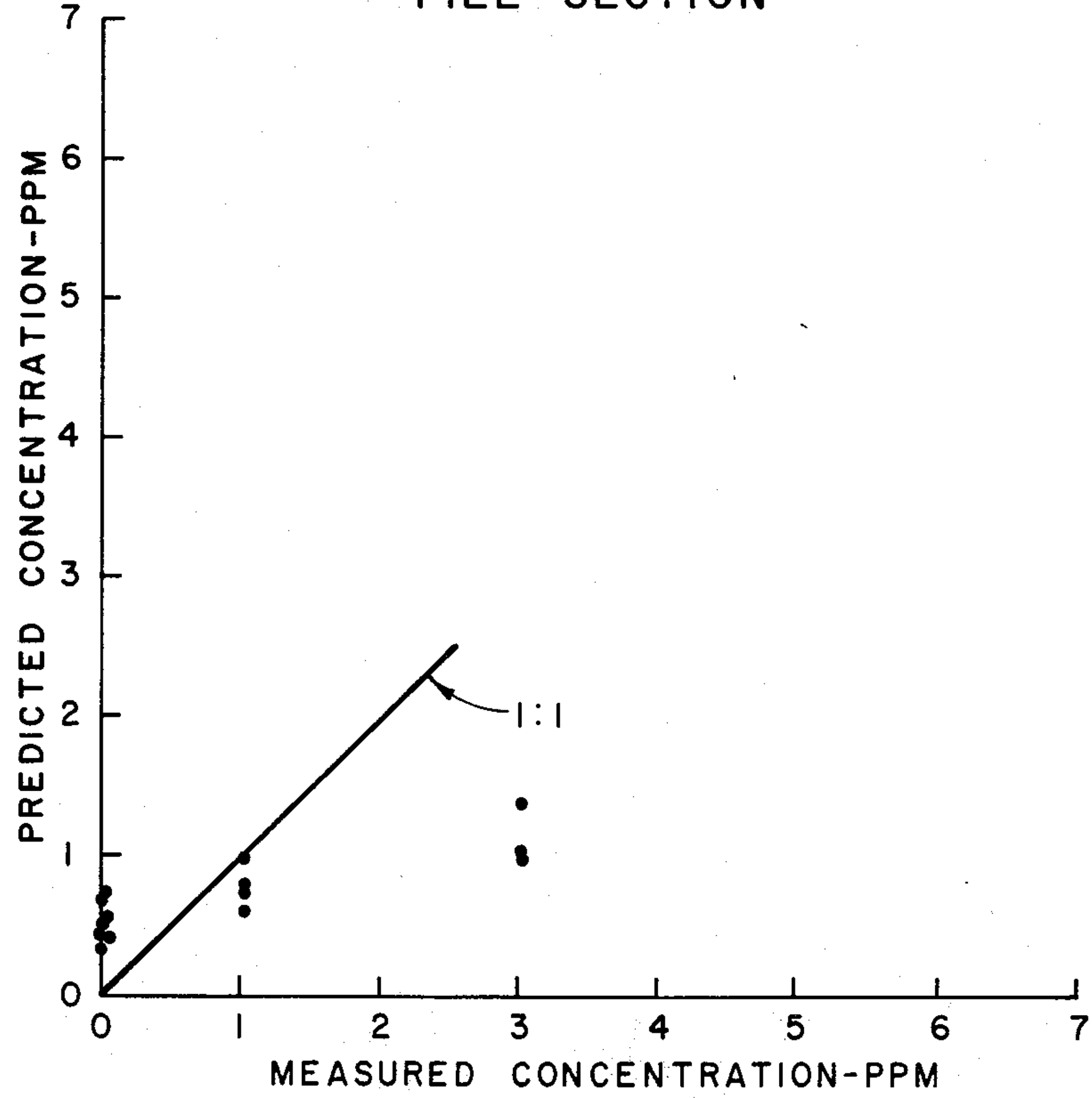
OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS—
CUT SECTIONS



SOURCE: S^3 REPORT

Figure 12-61

OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS—
FILL SECTION



SOURCE: S^3 REPORT

AIR QUALITY MANUAL MODIFICATION

Prepared by
Andrew Ranzieri and Gerald Bemis
Transportation Laboratory

Modification No. 1 - Revision to Line Source Dispersion Model for Depressed Sections

A major revision to the line source model(1) used to estimate microscale concentrations is described. This revision affects concentrations downwind from depressed sections for both cross and parallel wind conditions.

This revision constitutes an interim improvement in our method of analysis, based upon data from actual carbon monoxide measurements made in conjunction with our Federally-funded research project in Los Angeles. This modification affects all depressed sections (depth limited to 30 feet or less).

From our studies in the Los Angeles area, we have derived a mathematical relationship using regression techniques relating height above pavement to carbon monoxide concentrations as a function of surface stabilities for depressed sections only. The relationship was derived from heights above the pavement of four feet to 44 feet. These CO concentrations were measured in the median on the Santa Monica Freeway at the 4th Avenue Pedestrian Overcrossing and on the Harbor Freeway at the 146th Avenue Pedestrian Overcrossing.

Different relationships were derived for stability A, B and C-D combined. Not enough data were gathered for stability E and F due to meteorological conditions. Until further data are obtained, it will be assumed that the relationship derived for stability C-D can be used for stability E or F.

In order to incorporate this change in our microscale modeling analysis, we have developed a "CO Reduction Factor." This transposes the mixing cell concentration, on the highway within the depressed section, into an imaginary mixing cell at the same height as the surrounding terrain. The at-grade dispersion equation is then used to calculate concentrations downwind from the depressed section.

The "CO Reduction Factor" was derived from the CO concentrations measured at 4 feet, 12 feet, 20 feet, 36 feet or 44 feet, divided by the CO concentration at 4 feet. The CO Reduction Factor for

(1) Air Quality Manual CA-HWY-MR657082S-4-72-12 "Mathematical Approach to Estimating Highway Impact on Air Quality"

4 feet is 1.0 and the CO Reduction Factor for any height above 4 feet is less than 1.0. The following is the derived CO Reduction Factor:

$$\text{CO Reduction Factor} = 10^{RF}$$

where for Stability A,

$$RF=[-.18164-.01448(h)+1.439\text{x}10^{-5}(VPH)+7.9\text{x}10^{-4}(\emptyset)]$$

for Stability B,

$$RF=[.21754-.01431(h)-7.2\text{x}10^{-4}(\emptyset)-2.252\text{x}10^{-2}(\bar{U})]$$

and for Stability C thru F

$$RF=[.02019-.01382(h)+4.98\text{x}10^{-6}(VPH)-5.73\text{x}10^{-3}(\bar{U})]$$

In the above equations, h = the positive vertical distance between the roadway and the surrounding terrain in feet. The other parameters are the same as defined in the Air Quality Manual titled "Mathematical Approach to Estimating Highway Impact on Air Quality."

In almost all cases, the carbon monoxide concentration decreases with height. This decrease is gradual in the bottom 12 feet, reinforcing the concept that a uniform mixing cell concentration exists. There were, however, a few cases where aerodynamic eddies caused some increase of CO concentrations with height. These cases were excluded from the analysis and will be subject to future research.

In the latest subroutine (described below), the modified procedure for calculating carbon monoxide concentrations for <u>depressed sections</u> is as follows:

1) Calculate the mixing cell concentration in the same manner as before.

2) If, and only if, <u>a depressed section</u> is being analyzed, an equivalent at-grade mixing cell is created by multiplying the mixing cell concentration by the CO Reduction Factor.

   For example, for parallel winds (depressed section only):

Equation No. 8 of the manual titled "Mathematical Approach to Estimating Highway Impact on Air Quality",

$$C = (A)\left(\frac{Q}{\bar{U}}\right)\left(\frac{1}{K}\right)\left(\frac{30.5}{W}\right)$$

is to be supplemented with Equation No. 8A

$$C = (A)\left(\frac{Q}{\bar{U}}\right)\left(\frac{1}{K}\right)\left(\frac{30.5}{W}\right) \times (\text{FACTOR}).$$

Equation No. 8 is still used to predict concentrations on the highway within the mechanical mixing cell and Equation No. 8A is used in step 3 below to predict downwind concentrations.

3) The downwind concentration is calculated as before, with the exception that for depressed sections the equivalent at-grade mixing cell and the at-grade downwind dispersion equations are used. This allows the estimation of CO concentration from top of cut to any point further removed from the freeway. Some of these estimates were not available using the previous methods. For example, for parallel winds, at-grade receptor (depressed section only):

Equation No. 12 of the manual titled "Mathematical Approach to Estimating Highway Impact on Air Quality",

$$ppm = [ppm]_{M.C.} [\exp + \frac{1}{2}\left(\frac{Z_o}{\sigma_Z}\right)^2] [\exp - \frac{1}{2}\left(\frac{Y}{\sigma_Y}\right)^2],$$

is to be supplemented with Equation No. 12A

$$ppm = [ppm]_{M.C.} [\exp - \frac{1}{2}\left(\frac{Y}{\sigma_Y}\right)^2]$$

with the mixing cell term, $[ppm]_{M.C.}$, calculated according to Equation No. 8A in step 2, above.

Assumptions of the method (excluding previous assumptions in the air quality manuals):

1) The mixing cell heights for the depressed section and the equivalent at-grade section are the same.

2) The CO reduction factor determined for stability C-D will be used for stabilities E and F until future data are available for these stability conditions.

3) Aerodynamic eddies are not included in this analysis and will be subject to further research and validation (the largest allowable CO reduction factor is 1.0).

SECTION 13

REGIONAL AIR QUALITY MODELING

A. Uses of Regional Air Quality Models

A. Assess the impact of transportation systems on regional air quality.

B. Identify "hot spots" and locations of air monitoring stations for system planning.

C. Evaluate transportation control strageties.

D. Evaluate the interrelationship of land use, transportation and air quality planning.

II. Federal Regulations Requiring Regional Analysis

A. Clear Air Act of 1970
B. Federal Aid Highway Act
C. EPA Indirect Source Regulations
D. See Figure 13-1

III. Levels of Analyses for Regional Air Quality Modeling

A. Pollutant burden - Rollback (CO, NO_2, O_3)
B. Conservation of Mass - Photochemical (CO, NO_2, O_3)
C. Models predict above baseline levels - Figure 13-2

IV. Pollutant Burden Transportation System - Figure 13-3

A. Input Variables

1. Vehicle miles traveled on each link

2. Vehicle speed on each link
3. Emission factors for CO, HC, NO_x

B. Outputs - Tons per day

$$TPD = 1.1 \times 10^{-6} \text{ (VMT) (EF)}$$

C. Traffic Requirements

Speed (mph)	VMT	E.F.
10	-	-
20	-	-
30	-	-
40	-	-
50	-	-
60	-	-

D. Critical Year for Regional Transportation Analysis

1. Rate of traffic volume increase equals rate of decrease in emission factors.

2. Rate of traffic increase less than the rate of emission factor decrease.

E. Typical Outputs from Pollutant Burden Transportation Analysis

1. See Figures 13-4 through 13-7

V. Rollback

A. Assumptions - See Figure 13-8

B. Equation Figure 13-8

C. Predictions for O_3

1. $O_3 \propto$ RHC where RHC are emissions from stationary and mobile sources.

D. Example to Predict Future CO

Base year (1970) CO concentration (1 hr) = 50 ppm

Base year (1970) CO emissions (stationary + mobile) = 500 TPD

Future year (1980) CO emissions (stationary + mobile) = 250 TPD

$$\left(C_{max}\right)_{1980} = 50\left(\frac{250}{500}\right) = 25 \text{ ppm}$$

E. Example to Predict Future O_3

Baseline year (1970) O_3 concentration (1 hr.) = 0.40 ppm

Baseline year (1970) RHC (stationary + mobile) emissions = 700 TPD

Future year (1980) RHC (stationary + mobile) emissions = 300 TPD

$$(O_3)_{max} = 0.40\left(\frac{300}{700}\right) = 0.17 \text{ ppm}$$

F. Limitations of Rollbach for Primary and Secondary Pollutants

1. NO meteorological inputs

2. Cannot predict temporal or spatial distribution of pollutants

3. Does not include HC, NO_x and ultraviolet radiation for predicting O_3

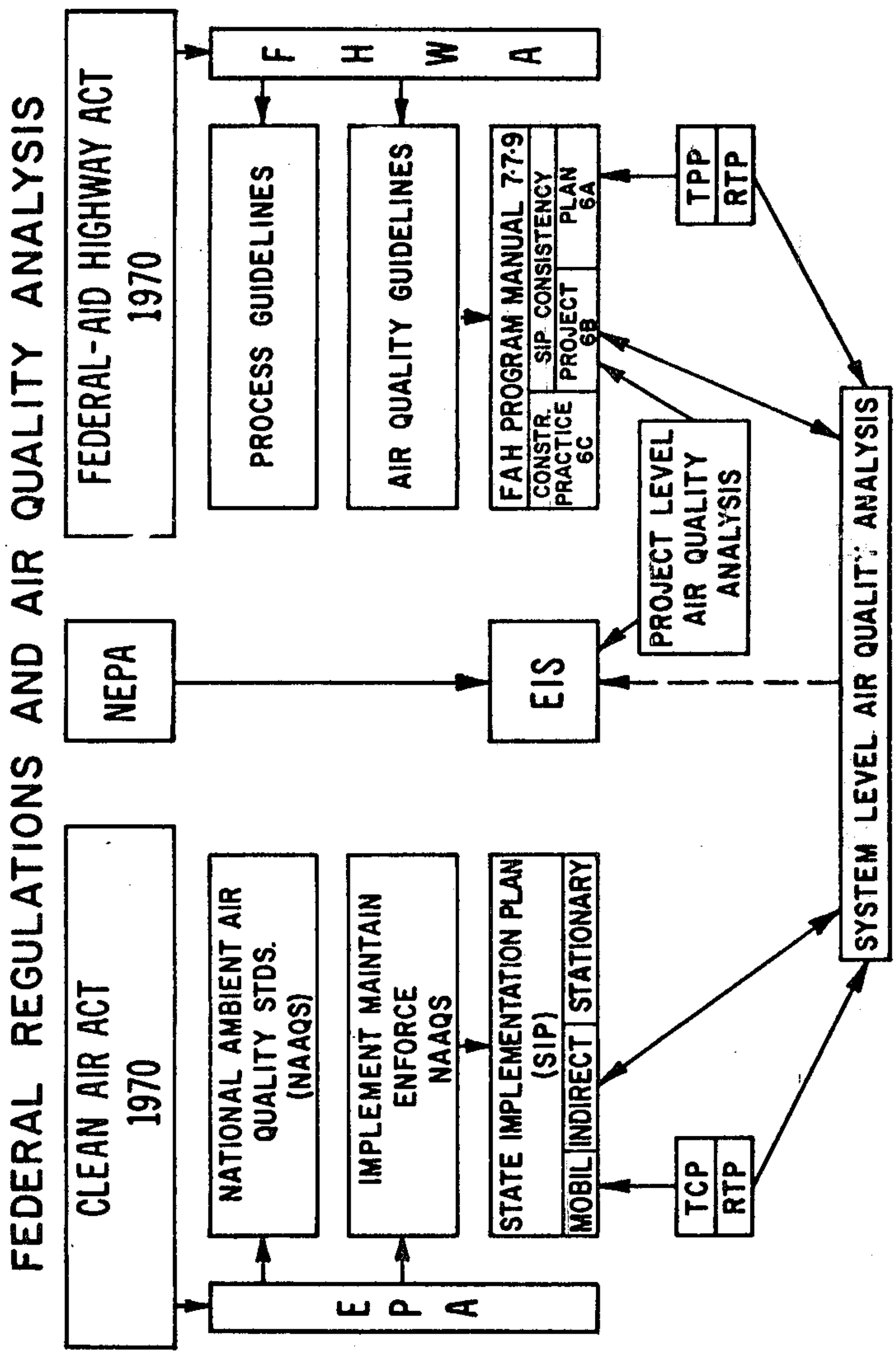
4. No information on spatial alternatives for transportation plans.

5. Different baseline years give different predictions for air quality

6. It is at best a first order of magnitude estimate

G. Rollback Techniques Using Larsen Model

1. See Figure 13-9



FEDERAL REGULATIONS AND AIR QUALITY ANALYSIS
CLEAN AIR ACT 1970
NEPA
FEDERAL-AID HIGHWAY ACT 1970
E P A
F H W A
NATIONAL AMBIENT AIR QUALITY STDS. (NAAQS)
IMPLEMENT MAINTAIN ENFORCE NAAQS
PROCESS GUIDELINES
AIR QUALITY GUIDELINES
STATE IMPLEMENTATION PLAN (SIP)
MOBIL
INDIRECT
STATIONARY
EIS
FAH PROGRAM MANUAL 7-7-9
CONSTR. PRACTICE 6C
SIP CONSISTENCY
PROJECT 6B
PLAN 6A
PROJECT LEVEL AIR QUALITY ANALYSIS
TCP
RTP
TPP
RTP
SYSTEM LEVEL AIR QUALITY ANALYSIS

FIGURE 13-1

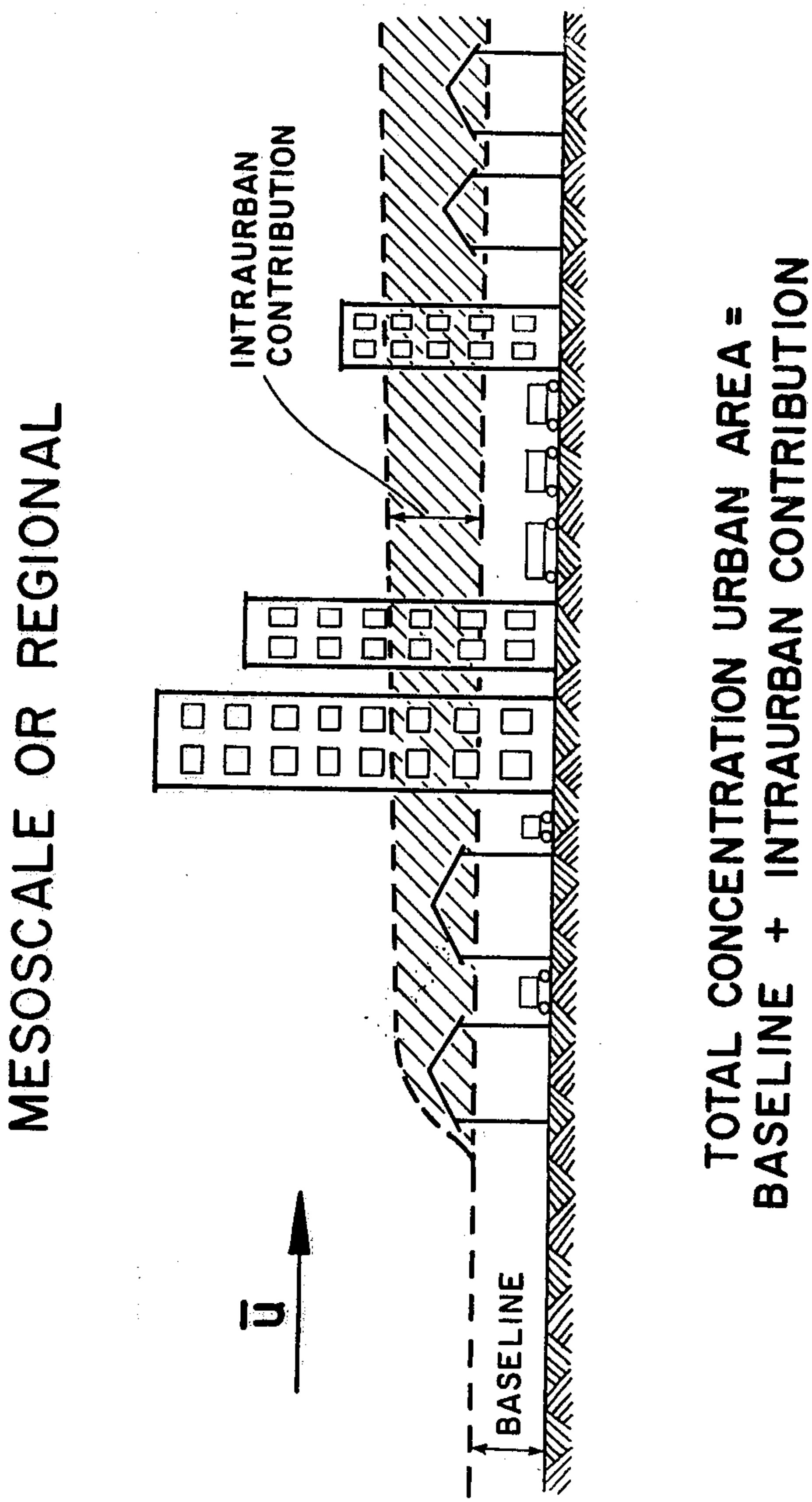

MESOSCALE OR REGIONAL
INTRAURBAN CONTRIBUTION
$\bar{U}$
BASELINE
TOTAL CONCENTRATION URBAN AREA =
BASELINE + INTRAURBAN CONTRIBUTION

FIGURE 13-2

MESOSCALE ANALYSIS

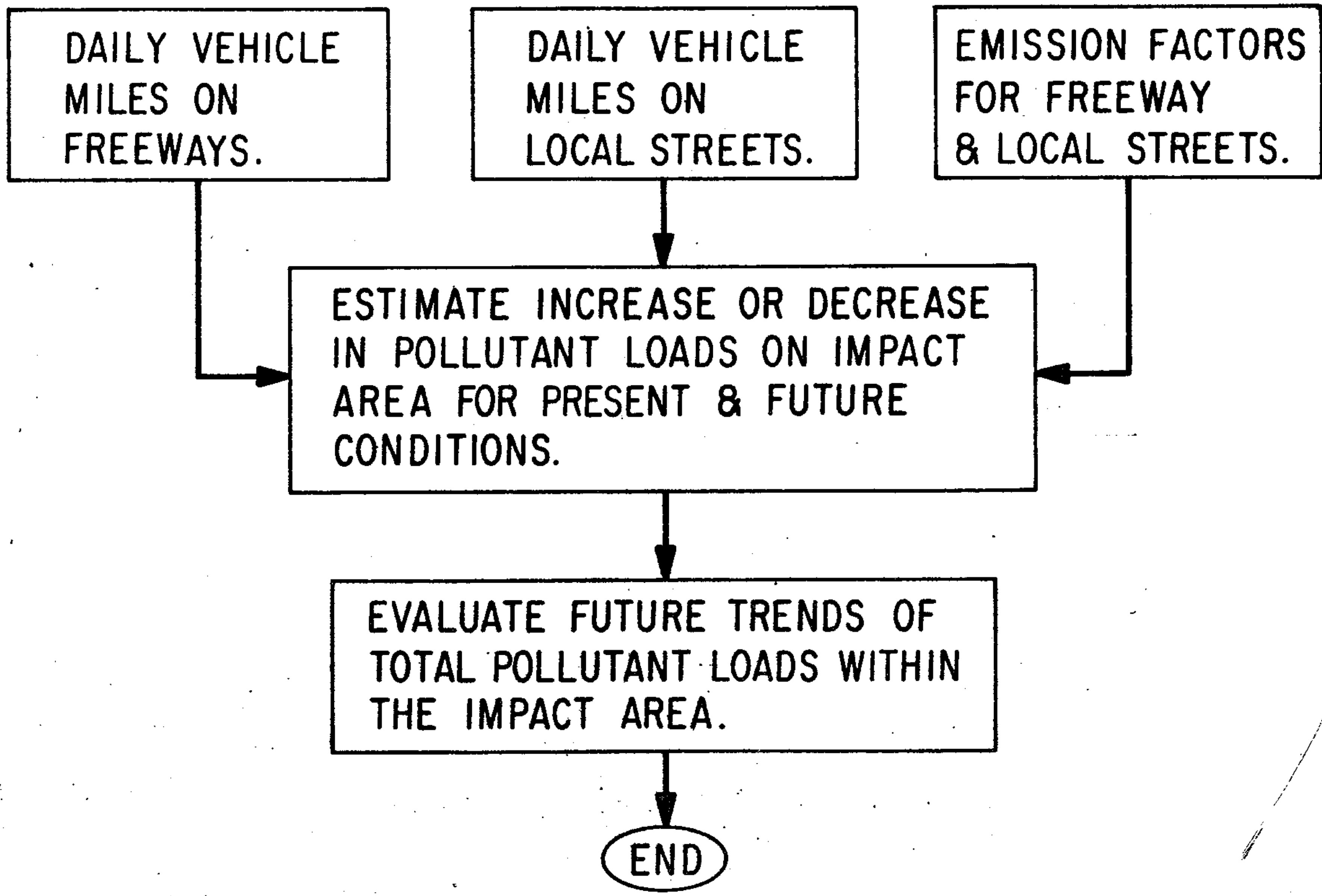


FIGURE 13-3

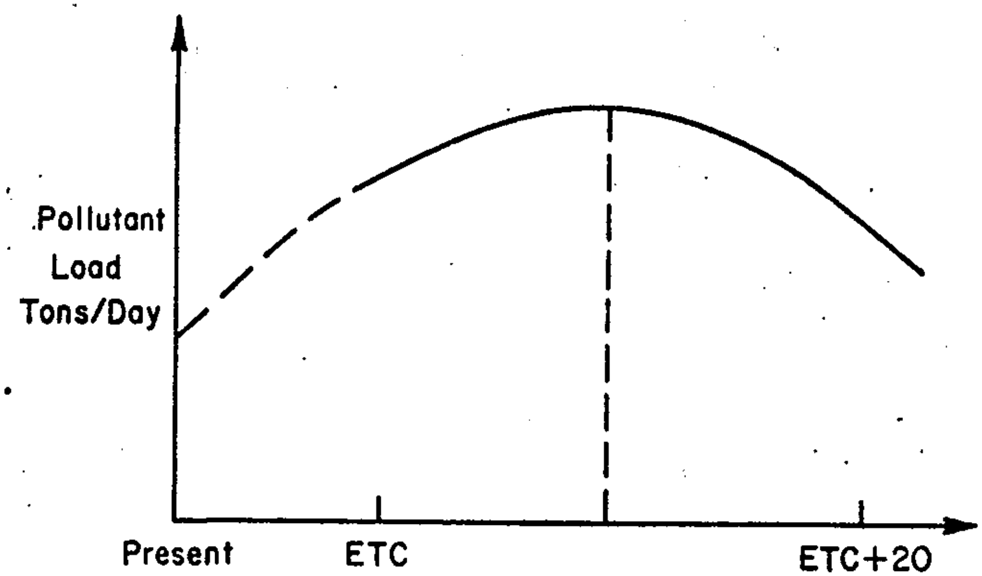
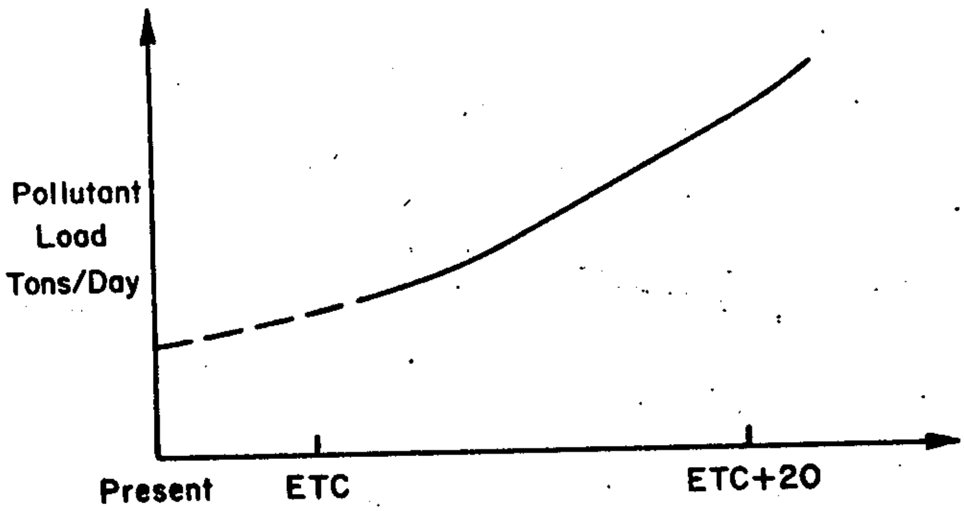


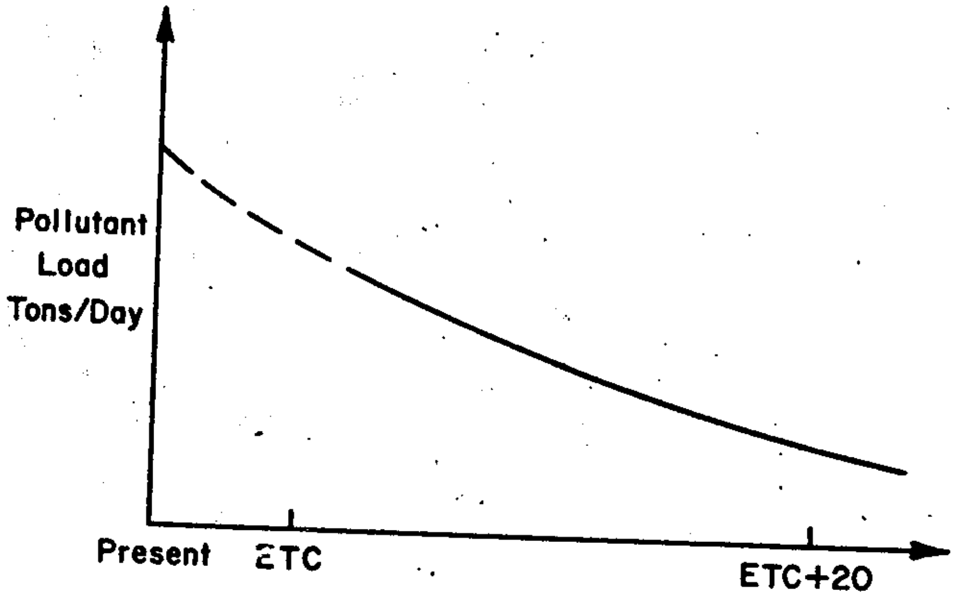
Fig. 10 CRITICAL YEAR OF POLLUTANT LOAD FOR MESOSCALE ANALYSIS

FIGURE 13 - 4



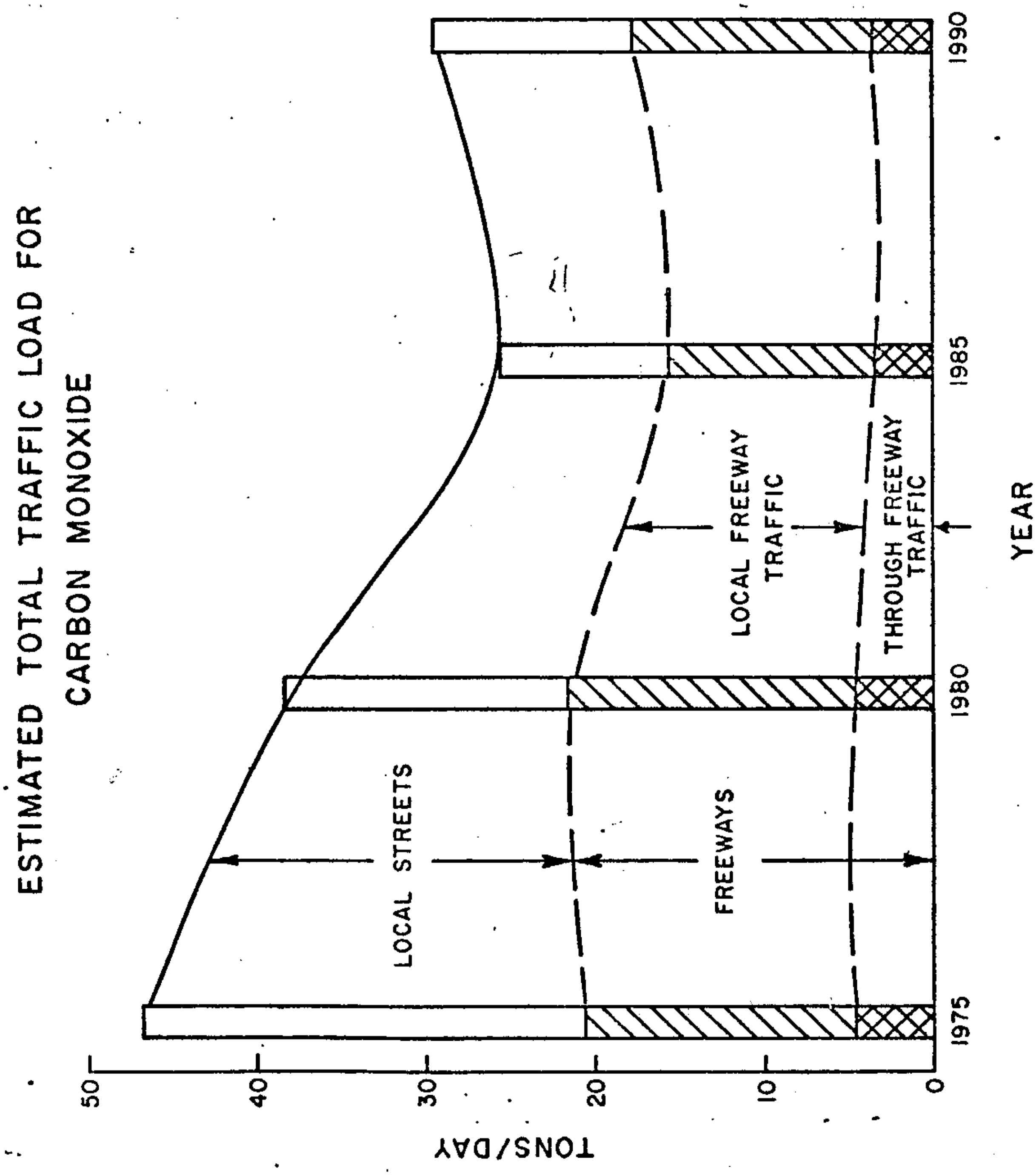
TRAFFIC INCREASE GREATER THAN EMISSION FACTOR DECREASE FOR MESOSCALE ANALYSIS

FIGURE 13-5



TRAFFIC INCREASE LESS THAN EMISSION FACTOR DECREASE FOR MESOSCALE ANALYSIS

FIGURE 13-6



ESTIMATED TOTAL TRAFFIC LOAD FOR
CARBON MONOXIDE
TONS/DAY
0
10
20
30
40
50
1975
1980
1985
1990
YEAR
LOCAL STREETS
FREEWAYS
LOCAL FREEWAY TRAFFIC
THROUGH FREEWAY TRAFFIC

FIGURE 13-7

PROPORTIONAL ROLLBACK MODEL

ASSUMPTIONS:

(1) LINEAR PROPORTIONALITY EXISTS BETWEEN REGIONAL EMISSIONS AND OBSERVED CONCENTRATIONS.

(2) SPATIAL AND TEMPORAL VARIATIONS OF EMISSIONS IN THE ANALYSIS YEAR ARE IDENTICAL TO THAT OF THE BASE YEAR.

(3) EMISSION SOURCES WITHIN THE REGION ARE REDUCED BY THE SAME PERCENTAGE AS A RESULT IN THE CONTROL STRATEGY.

$$C_{max} = \frac{\bar{E}_s}{\bar{E}_B} \times C_{B_{max}}$$

WHERE C_{max} = MAXIMUM FUTURE CONCENTRATION

$\bar{E}_s$ = AVG. DAILY EMISSIONS FORECAST UNDER THE STRATEGY

$\bar{E}_B$ = AVG. DAILY EMISSIONS CALCULATED FOR BASE YEAR (1970)

$C_{B_{max}}$ = MAXIMUM CONCENTRATION OBSERVED AT MONITORING SITE DURING THE BASE YEAR

FIGURE 13-8

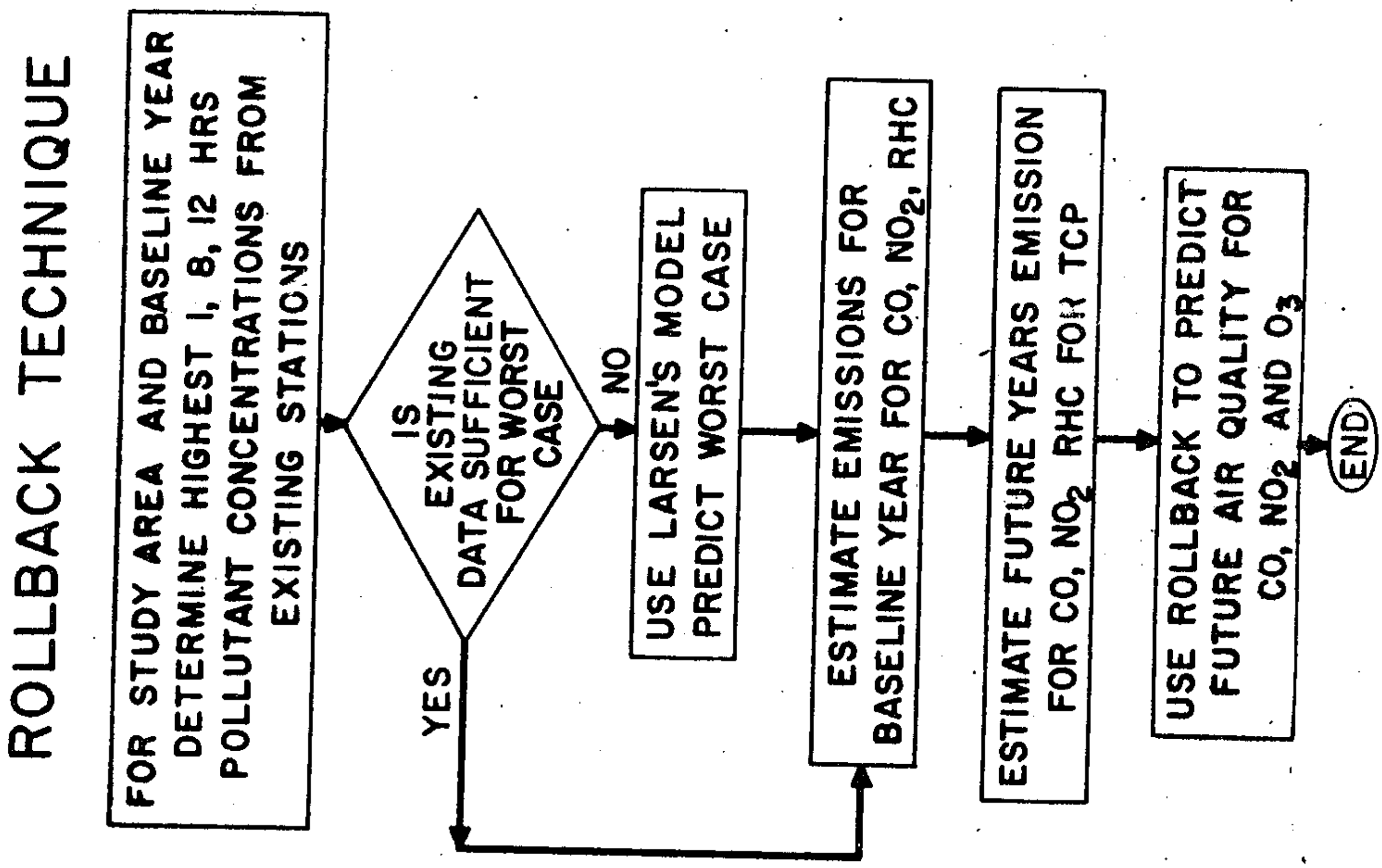

ROLLBACK TECHNIQUE
FOR STUDY AREA AND BASELINE YEAR DETERMINE HIGHEST 1, 8, 12 HRS POLLUTANT CONCENTRATIONS FROM EXISTING STATIONS
IS EXISTING DATA SUFFICIENT FOR WORST CASE
YES
NO
USE LARSEN'S MODEL PREDICT WORST CASE
ESTIMATE EMISSIONS FOR BASELINE YEAR FOR CO, NO_2, RHC
ESTIMATE FUTURE YEARS EMISSION FOR CO, NO_2, RHC FOR TCP
USE ROLLBACK TO PREDICT FUTURE AIR QUALITY FOR CO, NO_2 AND O_3
END

FIGURE 13-9

VI. SRI Regional Model

APRAC-1A*

A. Purpose

1. To estimate the CO concentrations for an urban area from readily available traffic and meteorological data

2. Model includes sources of:

   a. Extraurban diffusion from upwind sources.

   b. Intraurban diffusion from freeways, arterial and feeder street sources.

   c. Local diffusion of emissions within a street canyon.

*APRAC = Air Pollution Research Advisory Committee.
1A = refers to the present version of the model.

B. Traffic Data

1. Based primarily on CO emissions from a network of traffic road segments or links.

2. Primary network or link - all major freeway and surface arterial streets

3. Each link is identified by:

   a. ADT and VPH
   b. coordinate system
   c. road type

(1) freeway
(2) arterial
(3) local street

C. Secondary traffic network

1. Estimate total vehicle miles traveled on streets not representative by the primary network.

   a. total fuel consumption (entire area)
   b. less than DVM traveled on primary links
   c. secondary travel is distributed by relative traffic densities of local streets for each grid area.

D. CO Emissions

1. $E = \alpha S^{-B}$

   Where α & B are constants that depend on the characteristics of the emission control devices and vehicle mix.

   α & B are determined by plotting E.F. vs. speed on log-log paper (straight line)

   $E = \alpha S^{-B}$
   $\log E = \log B \log S$

   where $\log \alpha$ = intercept
   B = slope

2. Modify α & B based on California Department of Transportation emission factors or latest EPA study.

E. Intraurban Diffusion

1. Gaussian distribution of CO - See Figure 13-10

   a. σ_z represents the vertical spread of the plume. See Figure 13-11

2. Area segments are spaced logarithmically

   a. oriented normal to wind
   b. overlay traffic network

3. <u>Box model</u> - applied when elevated inversion exists.

F. Extraurban Diffusion

1. To estimate CO concentration from upwind sources.

$$C_e = \frac{5.15 \times 10^{-11} F}{\bar{U} h}$$

Where F = annual consumption of fuel gals per year with a 22.5° angular sector extending from 32 to 1000 KM upwind of receptor location.

2. Therefore input 16 sectors of fuel consumption.

3. $C = C_e + C_u$

   extraurban intraurban

4. C_e can be set equal to baseline levels from air quality survey. In this case, set F = 0

GENERAL GAUSSIAN EQUATION

$$\frac{C(X,Y,Z)\,\bar{U}}{Q} = \frac{1}{2\pi\sigma_Y\sigma_Z}\left[\mathrm{EXP}-\frac{1}{2}\left(\frac{Y}{\sigma_Y}\right)^2\right]\left[\mathrm{EXP}-\frac{1}{2}\left(\frac{Z+H}{\sigma_Z}\right)^2+\mathrm{EXP}-\frac{1}{2}\left(\frac{Z-H}{\sigma_Z}\right)^2\right]$$

C = CONCENTRATION

$\bar{U}$ = WIND SPEED

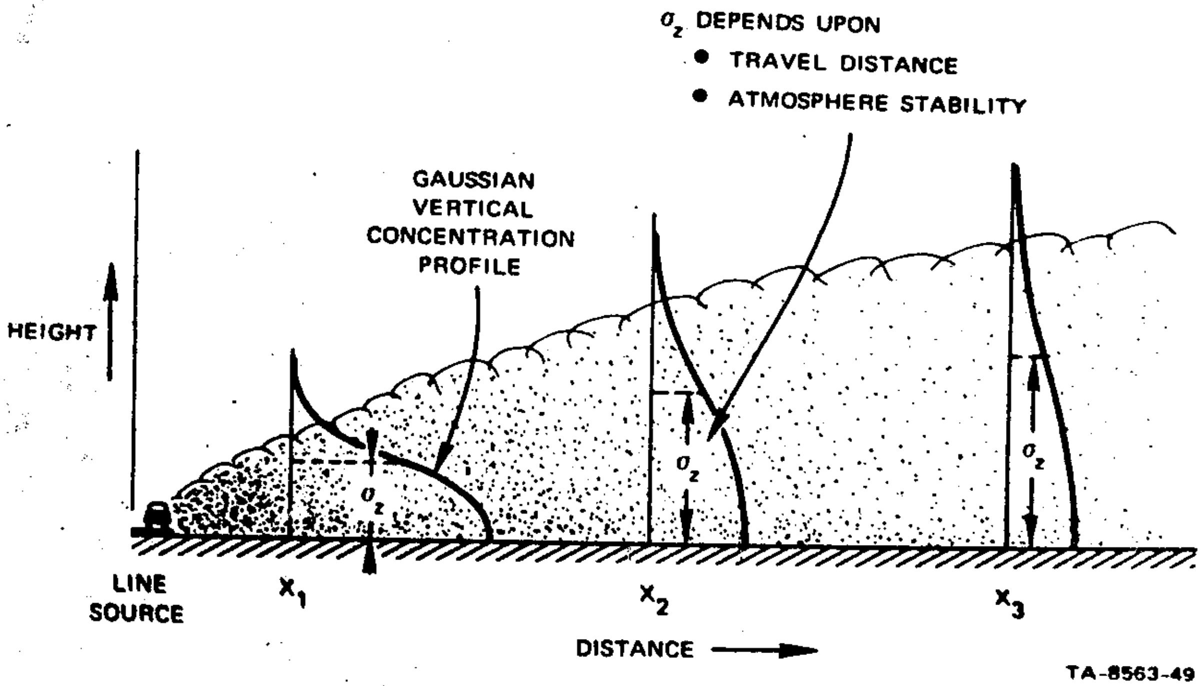
σ_Y, σ_Z = TURBULENCE PARAMETERS

Z = RECEPTOR HEIGHT

H = EFFECTIVE STACK HEIGHT

Y = RECEPTOR LOCATION FROM ℄ OF PLUME

FIGURE 13-10



VERTICAL DIFFUSION ACCORDING TO GAUSSIAN FORMULATION

is characterized by its standard deviation, σ_z. On the basis of experimental data, σ_z is taken to have the form

FIGURE 13-11

G. Local Street Canyon Diffusion

1. Street canyon effect
   (show overhead slide)

2. $C = \underbrace{C_e + C_u}_{\text{extra- \& intra-urban contribution}} + \underbrace{\Delta C}_{\text{street canyon effect}}$

H. Transport Wind, Mixing Depth and Stability

1. transport wind - use nearest airport
2. mixing depth

   a. closest USWB morning upper air sounding for temperature

   b. use maximum afternoon temperature at surface to predict maximum mixing depth

   c. morning or minimum mixing depth is determined using:

      (1) empirical relationship involving city size, urban and rural nighttime temperature

   d. hourly depths are <u>interpolated</u> based on observed hourly surface temperatures.

3. Stability index - basically Pasquill approach

   a. insolation
   b. wind speeds
   c. cloud cover

H. Changes in Model for Department of Transportation.

1. Input any desired maximum or minimum inversion height and interpolate for other hours

2. In street canyon option have building height as a variable

3. Input latest emission factors consistent with our present analysis

I. Basic Inputs

1. Options

a. Synoptic model - hourly CO concentrations as a function of time for comparisons and verification with observed concentrations. (10 receptor) or receptors.

b. Climatological model - frequency distribution or CO concentrations

c. Grid model - CO concentrations at various locations (up to 625)

d. Street canyon option for all cases above

2. Traffic

a. Coordinates all links in network
b. ADT, VPH
c. Type of roadway, freeway, street, etc.
d. Grid point spacing, usually 2 mi.sq.

e. Speed

f. Gasoline consumption

g. & B for emission factors

3. Meteorology

a. Maximum temperature for day

b. Minimum temperature for day

c. Temperature vs Pressure sounding

d. Surface wind speeds

J. Output

1. Digital output
2. Graphical display of CO contours

K. Validation

1. St. Louis
2. Chicago
3. San Jose
4. Sacramento - See Figures 13-12, 13-13, 13-14

L. Limitations of APRAC-1A Model

1. Good only for inert pollutants (CO)
2. Maximum 1200 links
3. Applicable for homogeneous areas with no topographic effects to alter surface winds
4. Not applicable for areas where a convergent or divergent wind flow field exists.
5. Assumes uniform wind flow over entire study area

SACRAMENTO AND VICINITY : BOUNDARIES OF APRAC STUDY

● RECEPTOR LOCATIONS : IN FIELD AND IN MODEL (1-9)

■ AIR RESOURCES BOARD (10)

AIRPORTS

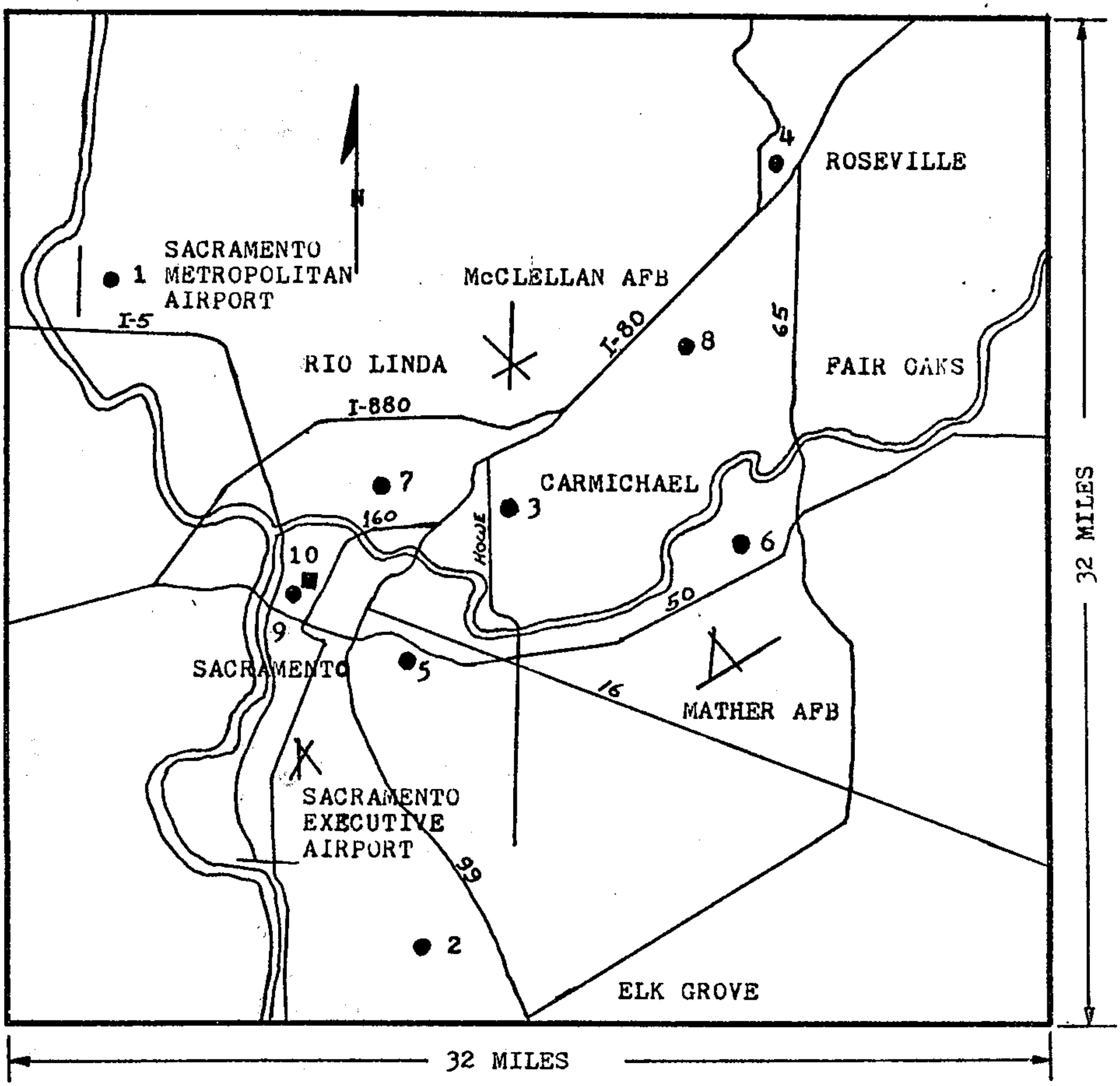


FIGURE 13-12

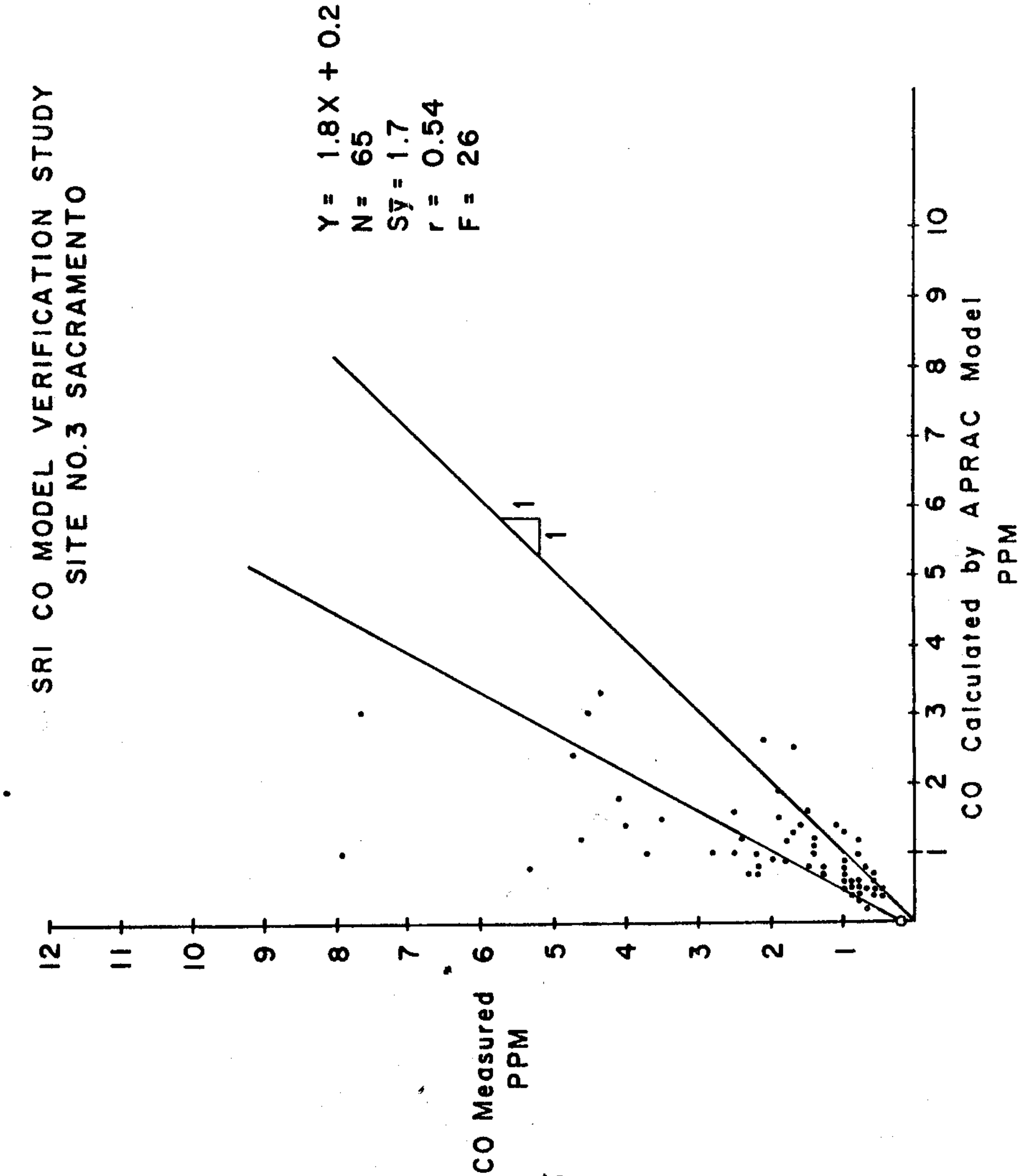

SRI CO MODEL VERIFICATION STUDY
SITE NO.3 SACRAMENTO
Y = 1.8X + 0.2
N = 65
Sȳ = 1.7
r = 0.54
F = 26
CO Measured
PPM
CO Calculated by APRAC Model
PPM
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
1
1

FIGURE 13-13

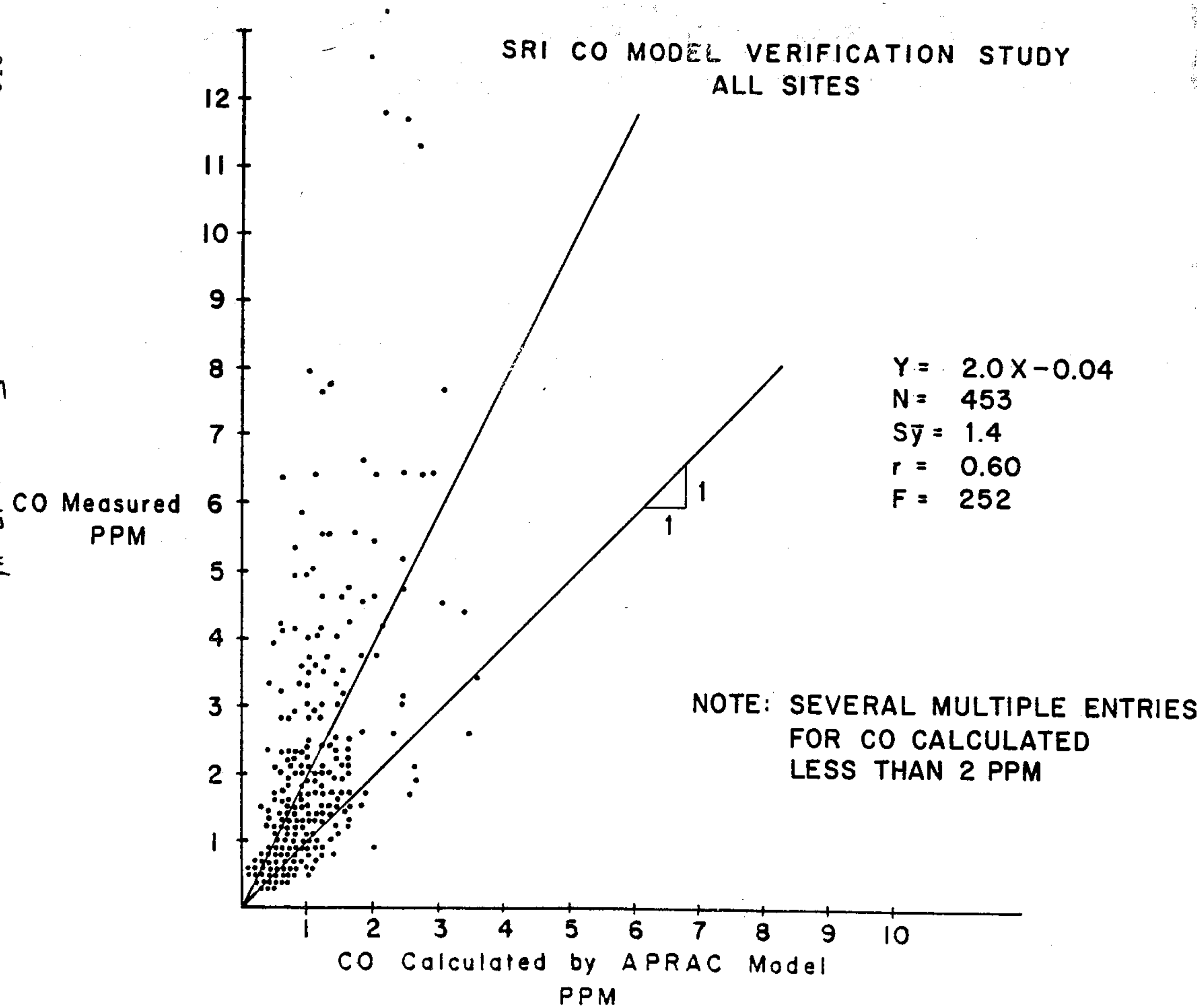

SRI CO MODEL VERIFICATION STUDY
ALL SITES
Y = 2.0 X − 0.04
N = 453
Sȳ = 1.4
r = 0.60
F = 252
NOTE: SEVERAL MULTIPLE ENTRIES
FOR CO CALCULATED
LESS THAN 2 PPM
CO Measured
PPM
CO Calculated by APRAC Model
PPM
1
1
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE 13-14

M. Advantages

1. Simulates multi-day run easily
2. Computationally efficient
3. Provides information for location of CO stations for system planning.

VII. Photochemical Models

A. SAI Airshed Model - grid or eulerian model
B. GRC - DIFKIN trajectory model
C. PES - trajectory model
D. Operation of Photochemical Model

1. Divide Area into grids - Figure 13-15

2. Each grid must specify:

a. Emission fluxes of HC, NO_x, CO
b. Wind flow field and inversion characteristics
c. Initial concentrations of HC, NO_x, CO

3. Identify terrain features that will alter surface winds

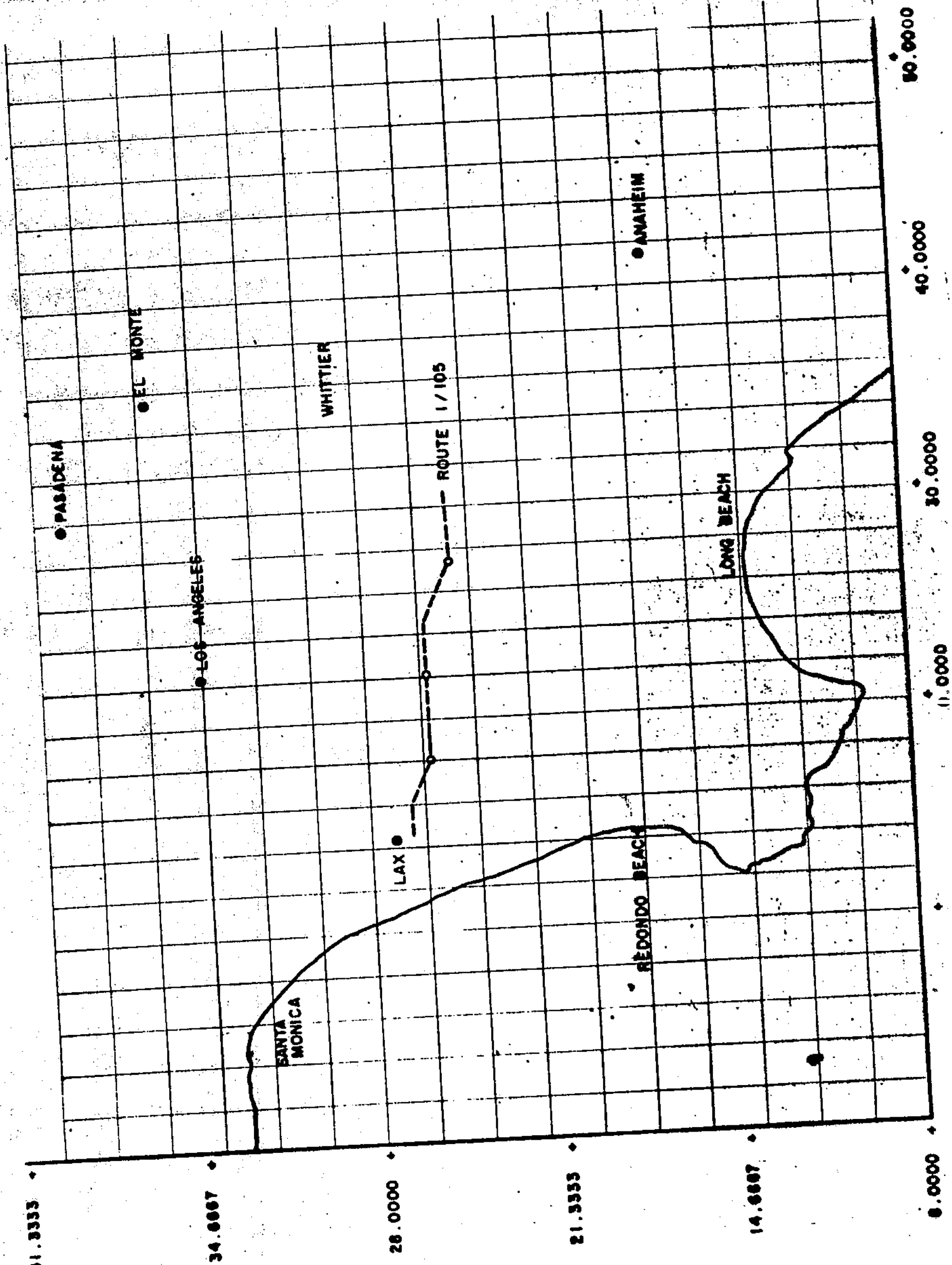
4. Simulate real world transport, diffusion and reactions in atmosphere.

VIII. DIFKIN - Diffusion and Kinetics

A. Purpose - a predictive model to assess air pollution effects on a regional scale using trajectories.

1. Model air pollutants from:

a. Distributed transportation sources - networks of highways and surface streets



320

FIGURE 13-15

b. point sources - industrial plants

B. Model Characteristics

1. Lagrangian model coupled with vertical diffusion and chemical reactions.

2. Air parcel carries its own set of coordinates in a trajectory aligned with the wind direction and traveling at the prevailing horizontal wind speed.

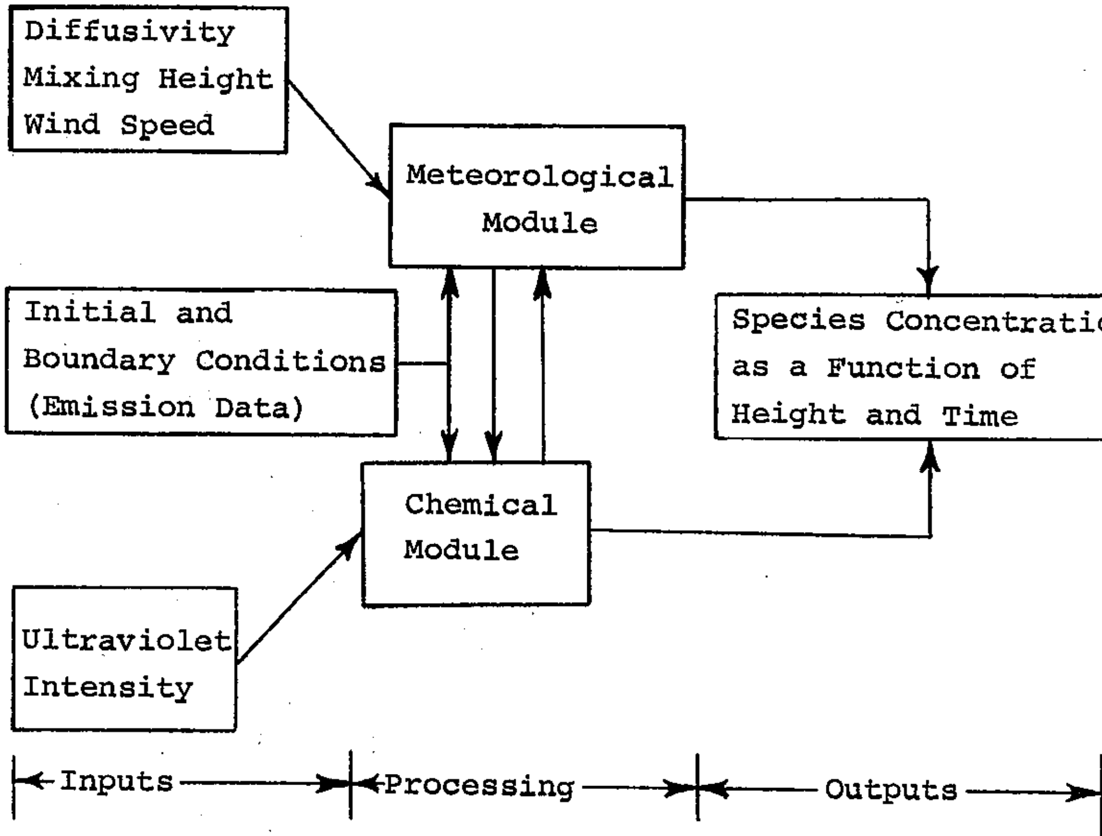
3. DIFKIN computes the time dependent behavior of a moving air parcel in which a multicomponent gaseous mixture undergoes simultaneous diffusion and chemical reactions.

C. Basic Equation

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = \frac{\partial}{\partial x}\left[D_z \frac{\partial c}{\partial z}\right] + R$$

Where: C = mass concentration
t = time
u = horizontal wind speed
x = downwind distance
z = height above ground
D = vertical turbulent diffusion coefficient; function of time and z
R = production rate

C. DIFKIN Flow Diagram



D. Meteorological Data Inputs

1. Surface wind speed as a function of time.

2. Mixing depth (inversion height) above ground surface.

3. Diffusivity coefficient = f (t,z)
units - m^2/min 10 to 3000 m^2/min

4. Ultraviolet intensity - is input implicitly via the rate constant for the photo-disassociation of NO_2.

E. Emission Data Inputs

1. Transportation systems - highways, etc.
2. Point sources
3. Grid source analysis
4. Initial boundary conditions

   a. Emission data at ground surface
   b. Emission data at top of inversion

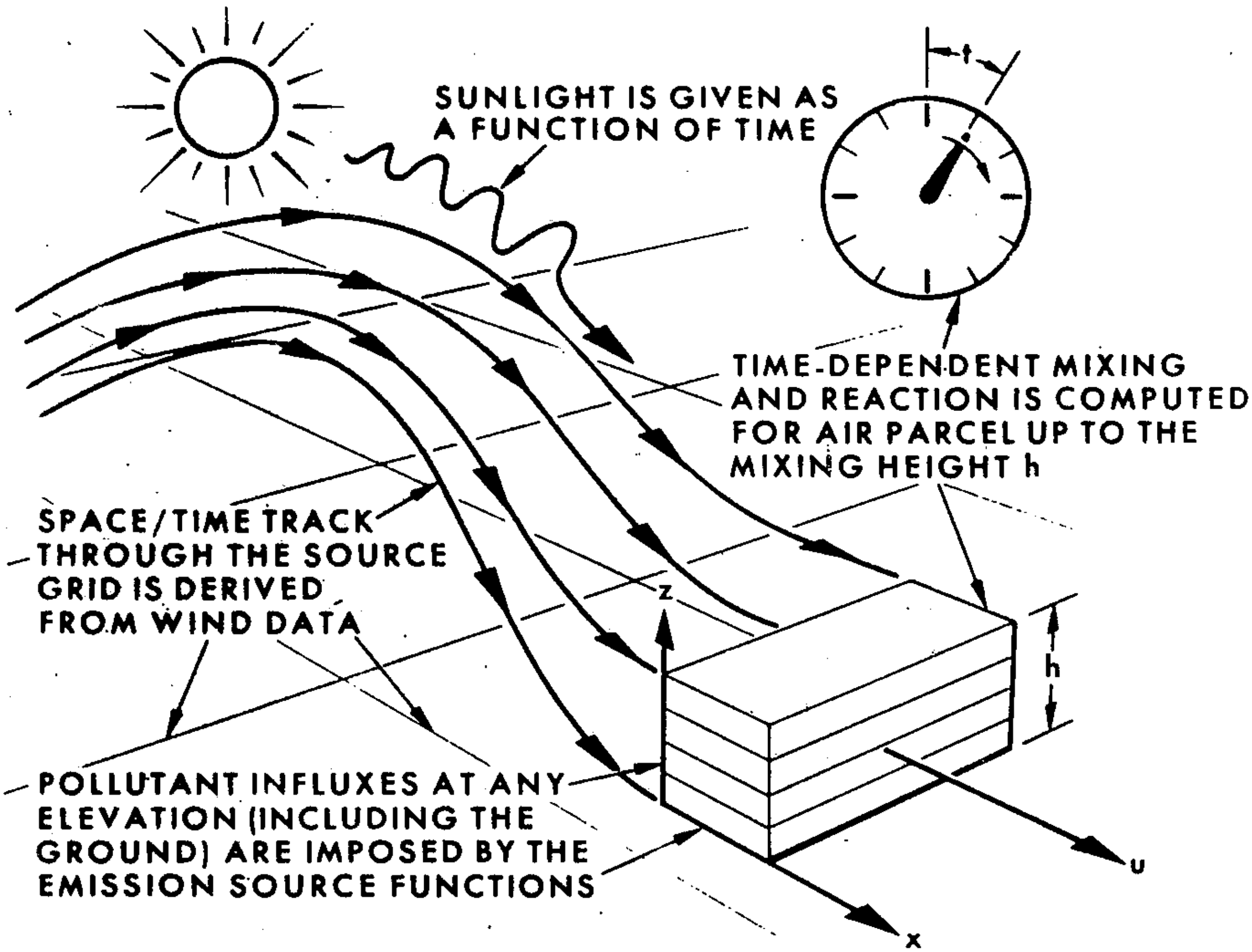
F. Chemical Rate Constants:

1. Nitric Oxide
2. Nitrogen Dioxide
3. Hydrocarbons
4. Carbon Monoxide
5. Ozone
6. Peroxyacetylnitrate (PAN)
7. Nitrous Acid
8. Nitric Acid
9. Hydroxyl Radical
10. Organic Radicals
11. Nitrogen Trioxide

G. Output of DIFKIN Model

1. Tabular Data
2. Graphical Data
3. Punched Output

H. Operation of Model - See Figure 13-16



Schematic of Diffusion Model for Air Pollution Simulation

FIGURE 13-16

I. Applications of DIFKIN

1. Applicable for project level analysis. See Figures 13-17 and 13-18.

2. Locate sources which produce "hot spots" for pollutant emissions using backward trajectories.

3. Predict pollutant concentrations in valleys.

4. Applicable for areas where terrain affects surface winds.

5. Computationally efficient

J. Limitations

1. Not directly applicable for convergence or divergence of wind flow fields.

2. Not applicable where vertical wind shear is an important parameter - multi-day runs.

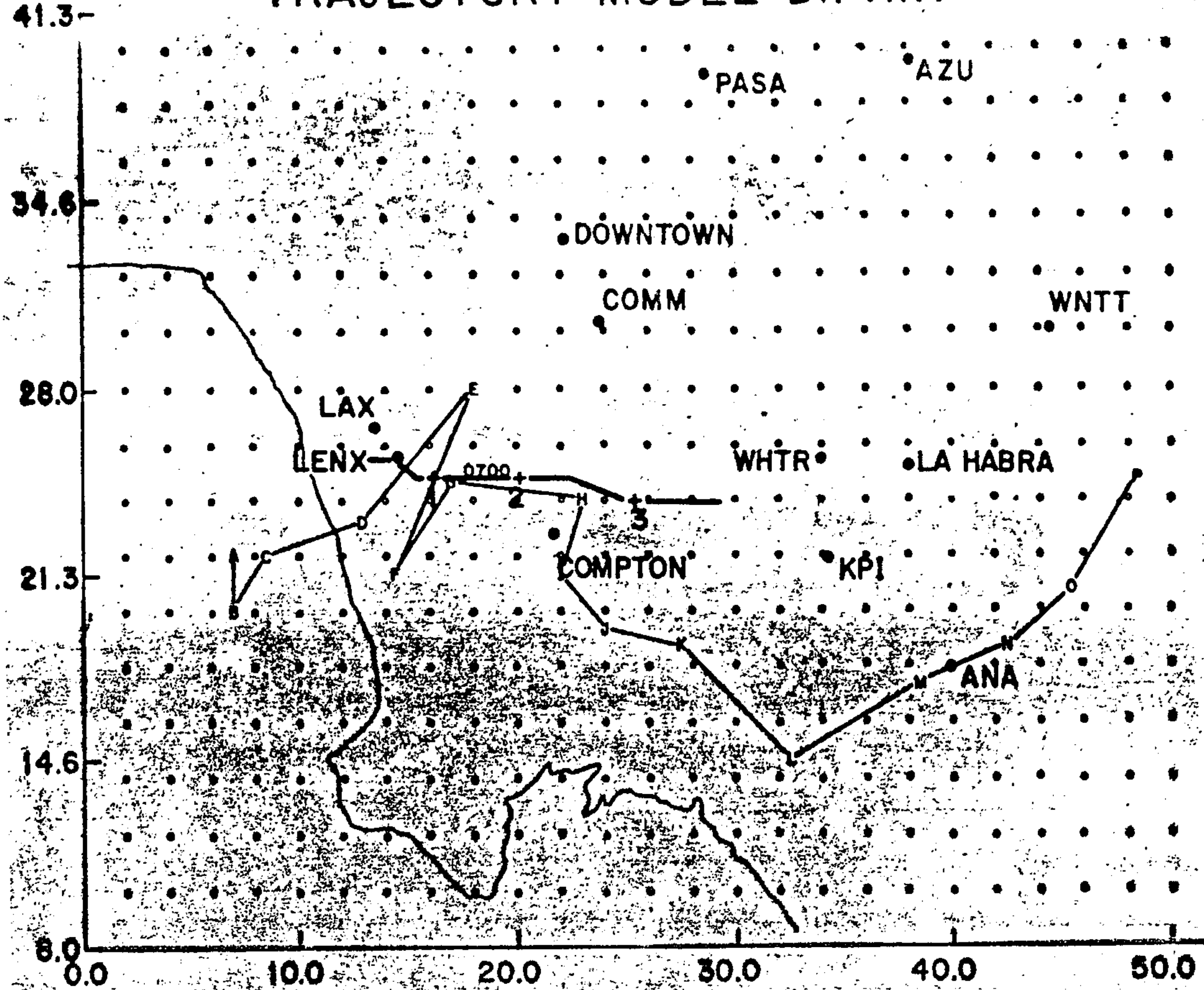
3. Not applicable for transportation system planning.

4. Difficult to compare prediction to 1 hour NAAQS because moving trajectories - spatial average.

5. Trajectories are sensitive to exposure of existing wind stations; therefore must have weather stations located consistent with assumptions of the model.

6. Input requirements.

TRAJECTORY MODEL DIFKIN



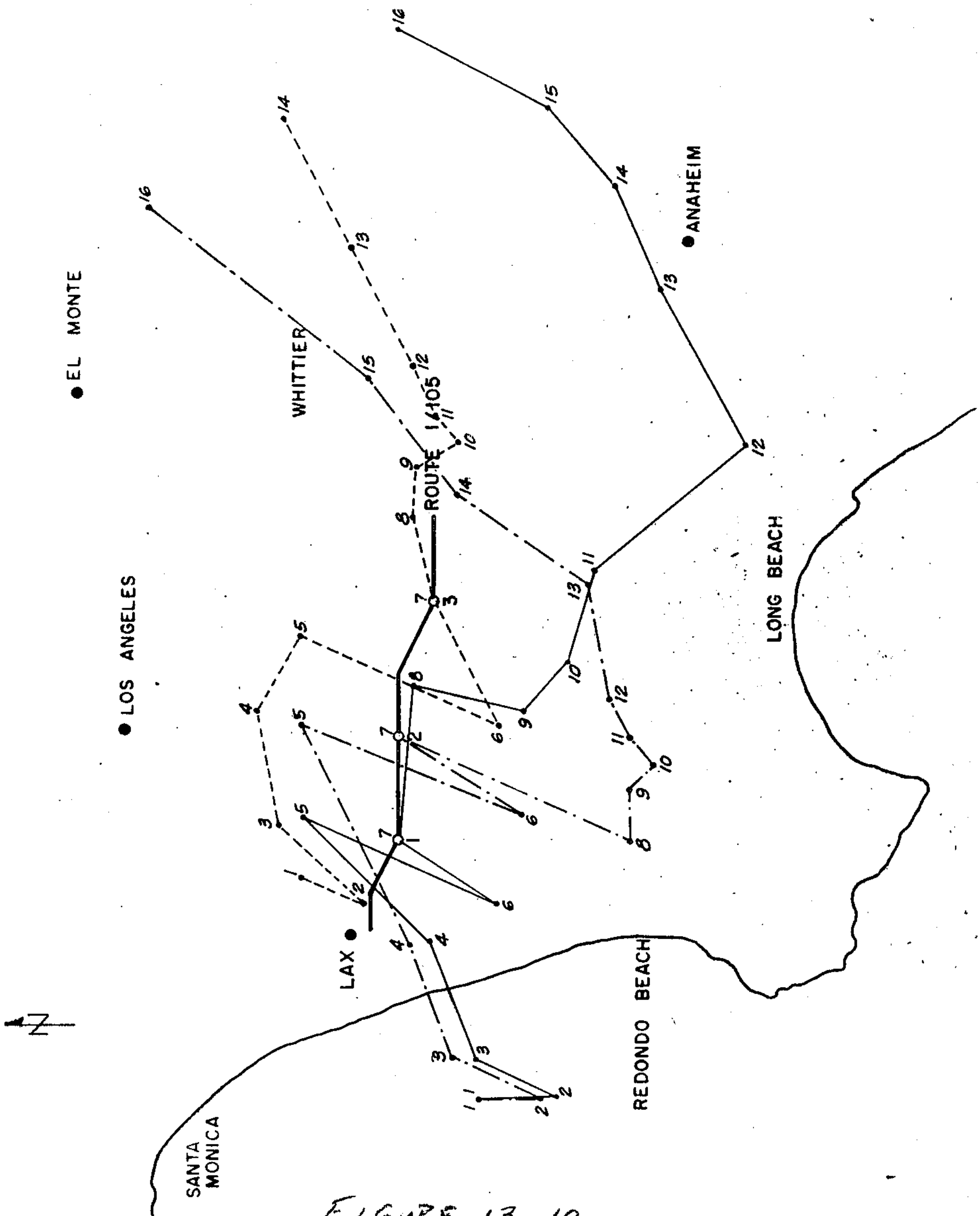

EL MONTE
WHITTIER
LOS ANGELES
ANAHEIM
ROUTE I 405
LONG BEACH
LAX
REDONDO BEACH
SANTA MONICA
N

FIGURE 13-18

IX. SAI Airshed Model

A. Purpose - A predictive model to assess air pollution impacts on a regional scale using an eulerian coordinate system.

1. Model air pollutants from:

   a. distributed transportation sources - network of highways and surface streets.

   b. point sources - industrial plants

   c. aircraft sources

B. Model Characteristics

1. Eulerian model coupled with three dimensional diffusion and chemical reactions; allows wind convergence and divergence and elevated behavior to be all treated readily in this forumulation

2. Predicts temporal and spatial distribution of pollutants for each grid in entire study area.

C. Basic Equation:

$$\frac{\partial c_i}{\partial t} + u\frac{\partial c_i}{\partial x} + v\frac{\partial c_i}{\partial y} + w\frac{\partial c_i}{\partial z} =$$

$$\frac{\partial}{\partial x}\left[K_H\frac{\partial c_i}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_H\frac{\partial c_i}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_z\frac{\partial c_i}{\partial z}\right] + R_i + S_i$$

Where C_i = concentration of species i

U, V, W = wind components in x, y, z direction

Kh, Kv = horizontal and vertical diffusivity

R_i = rate of production of species i through chemical reactions.

S_i = rate of production of species i from source emissions.

D. System Overview - See Figure 13-19

E. Automated Meteorological Data Preparation Program (AMDPP)

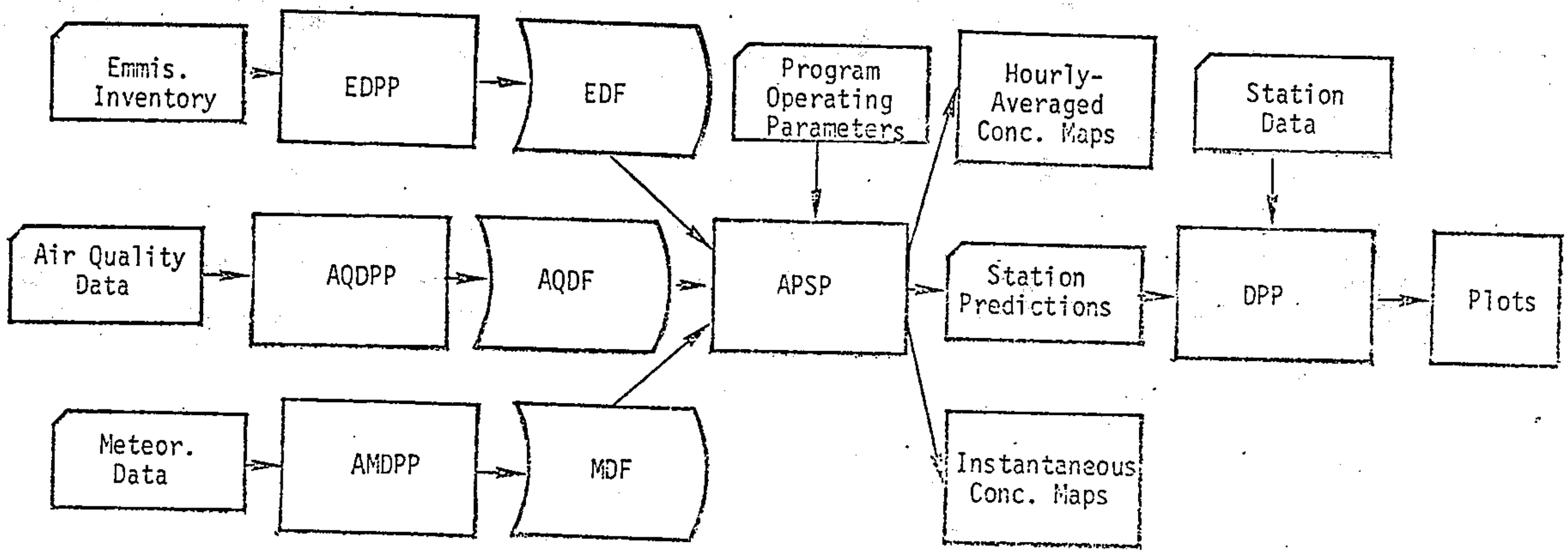
1. Purpose - The AMDPP is used to prepare meteorological data in a suitable format for direct input to the Atmospheric Pollution Simulation Program. Wind data and inversion soundings at points scattered throughout the modeling region are employed in an interpolation scheme which results in the calculation of wind speed and direction and mixing depth at each grid cell.

2. Input Data Requirements - Grid coordinates of each measurement site.

   Hourly-averaged wind speed and direction data
   Inversion soundings (as available)
   Miscellaneous program operating parameters.

3. Output Capabilities - Printed maps displaying the spatial distribution of the wind speed, wind direction, and mixing depth at each hour.

SYSTEM FLOW DIAGRAM



AMDPP - Automated Meteorological Data Preparation Program

APSP - Atmospheric Pollution Simulation Program

AQDF - Air Quality Data File

AQDPP - Air Quality Data Preparation Program

DPP - Data Plotting Program

EDPP - Emissions Data Preparation Program

EDF - Emissions Data File

MDF - Meteorological Data File

FIGURE 13-19

F. Emissions Data Preparation Program (EDPP)

1. Purpose - The EDPP is employed to process motor vehicles, aircraft, and fixed source emissions data. Total emissions for each chemical species are calculated at every grid point as a function of the time and placed in the Emissions Data File (EDF) in a form suitable for use by the Atmospheric Pollution Simulation Program.

2. Input Data Requirements

Motor Vehicle Emissions

- daily vehicle miles travelled (VMT) on surface streets in each ground level grid cell (miles/day)
- daily VMT traveled on freeways in each grid cell (miles/day)
- average freeway and city street driving speed in each cell as a function of time
- temporal distributions for both surface street and freeway driving activity
- average hot and cold-start vehicle emission factors for HC, NO_x, and CO (grams/vehicle-day)
- reactive/unreactive hydrocarbon split for exhaust emissions

Aircraft Emissions

- emission factors for each aircraft class as a function of operating mode (lb./minute)

- amount of time each class of aircraft spends in each operating mode (minutes)

- average number of engines of each class of aircraft

- airport location

- total number of daily ground operations at each airport (operations/day)

- temporal distribution of ground operations at each airport

Fixed Source Emissions

- total emissions rate of HC, NO_x, and CO from fixed sources into each grid cell (kgm/hour)

3. Output Capabilities - Printed maps displaying the spatial distribution of reactive and unreactive hydrocarbon, NO, NO_2, and CO emissions at each hour

G. Air Quality Data Preparation Program (AQDPP)

1. Purpose - The AQDPP takes either measured or user-specified air quality data at a number of scattered sites throughout the modeling region and, through an interpolation procedure, computes both the initial and boundary concentration distributions for use in the airshed simulation.

2. Input Data Requirements

Grid coordinates for each measurement site

Hourly air quality data (measured or user-specified) for each pollutant species at each station

Miscellaneous program operating parameters

3. Output Capabilities

Printed maps displaying the initial concentration distribution on the grid for each species.

Printed tables illustrating the calculated hourly values of the boundary concentrations for each species.

H. Atmospheric Pollution Simulation Program (APSP)

1. Purpose

The APSP is used to carry out the actual airshed simulation. Emissions, meteorological and air quality inputs are processed to yield the spatial and temporal distributions of air contaminants throughout the modeling region. Of particular interest are the estimates of hourly-averaged ground level pollutant concentrations for reactive hydrocarbons, unreactive hydrocarbons, NO, NO_2, O_3, and CO.

2. Input Data Requirements

Meteorological Data File
Emissions Data File

Air Quality Data File

Modeling region characteristics

- .maximum number of grid cells in each coordinate direction
- .shape of the region
- .topographic barriers

Chemical kinetics parameters

- .reaction rate constants
- .stoichiometric coefficients
- .temporal characteristics of photolysis rate constants

Miscellaneous program operating parameters

- .starting and stopping time of the simulation
- .integration time step size
- .time interval between ground level concentration map printouts

3. Output Characteristics

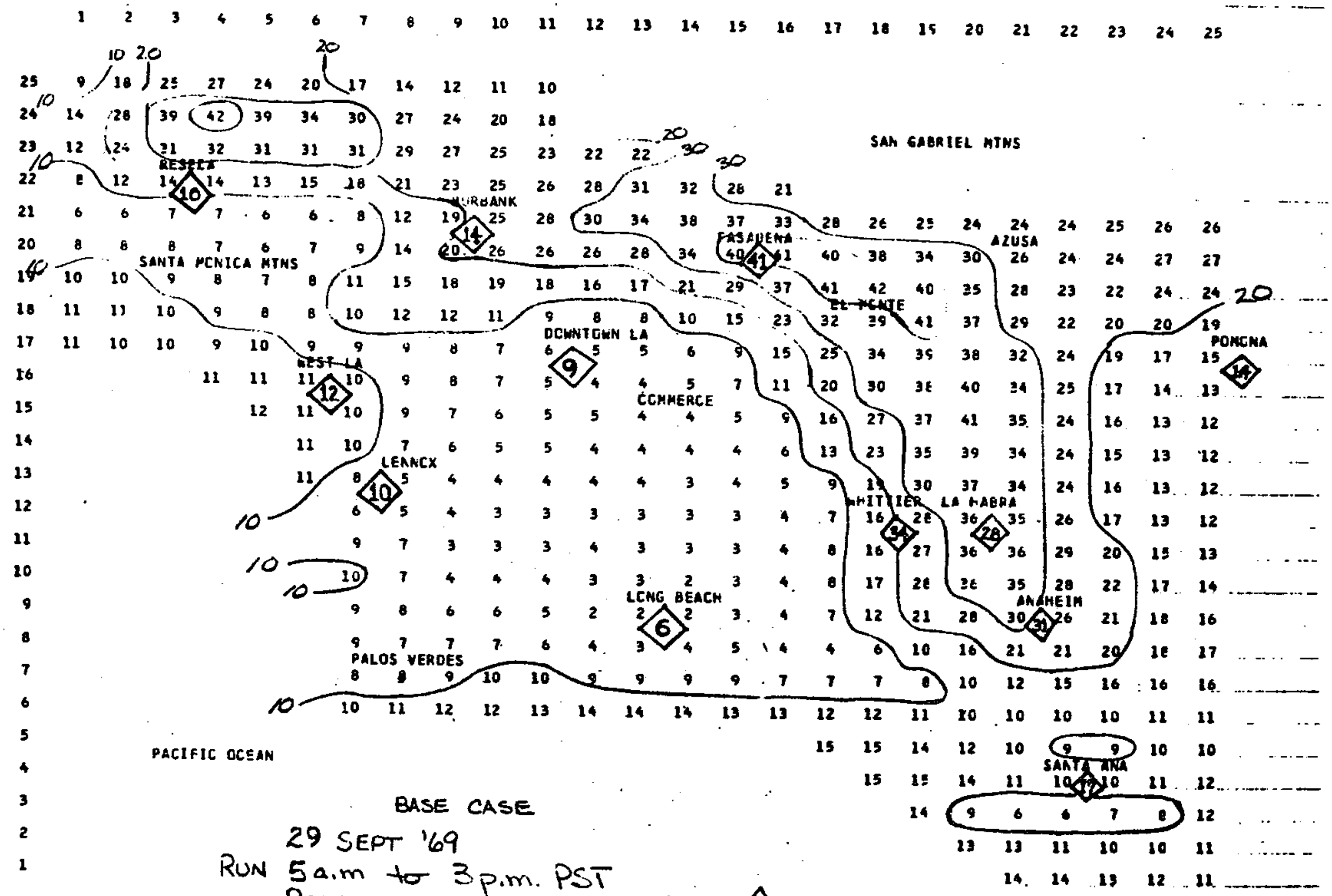
   Printed maps illustrating predicted ground level concentrations at regular time intervals (user-selected) throughout the course of the simulation See Figures 13-20 and 13-21

E. Applications of SAI Airshed Model

1. System planning to determine the interrelationship of land use, transportation and air quality planning.

GRID MODEL SAI

AVERAGE GROUND LEVEL CONCENTRATIONS (PPHM) OF O3 BETWEEN THE HOURS OF 1100. AND 1200. PST



BASE CASE

29 SEPT '69

RUN 5 a.m to 3 p.m. PST

ROTH EMISSIONS INVENTORY (1970)

◇ MONITORING STATION

FIGURE 13-20

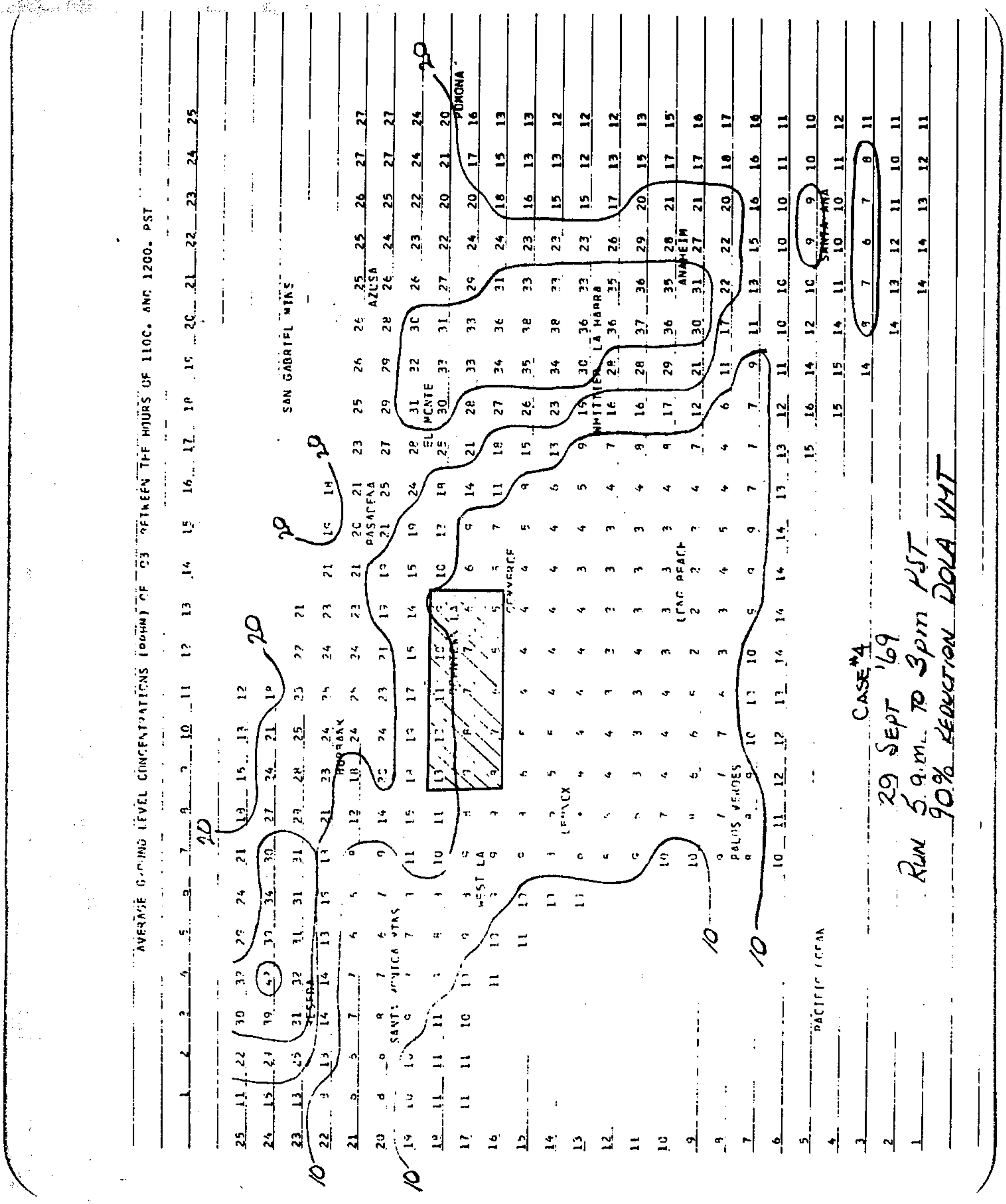

AVERAGE GROUND LEVEL CONCENTRATIONS (PPHM) OF O3 BETWEEN THE HOURS OF 1100. AND 1200. PST
SAN GABRIEL MTNS
AZUSA
POMONA
PASADENA
EL MONTE
WHITTIER
LA HABRA
ANAHEIM
SANTA ANA
LONG BEACH
PALOS VERDES
WEST LA
PACIFIC OCEAN
CASE #4
29 SEPT '69
RUN 5 9 a.m. TO 3pm PST
90% REDUCTION DOLA VMT

FIGURE 13-21

2. Applicable for areas where terrain effects alter surface winds.

3. Applicable for area where a convergence or divergence of wind flow field exists.

4. Applicable for areas where vertical wind shear is important.

5. Provides information for system planning and location of air monitoring stations.

F. Limitations of SAI Airshed Model

1. Expensive to run
2. Not applicable for project level analysis - too costly
3. Numerical diffusion problems
4. Cannot simulate multi-day runs - must be modified
5. Input requirements

G. Transportation Systems Analysis

1. See Figure 13-22

X. Validation of Regional Air Quality Models

A. DIFKIN, SAI, PES - Los Angeles Study

1. Poor data base for model inputs

2. Location of APCD stations where locally affected by:

a. high traffic densities
b. O_3 depression

FLOW CHART SYSTEM ANALYSIS

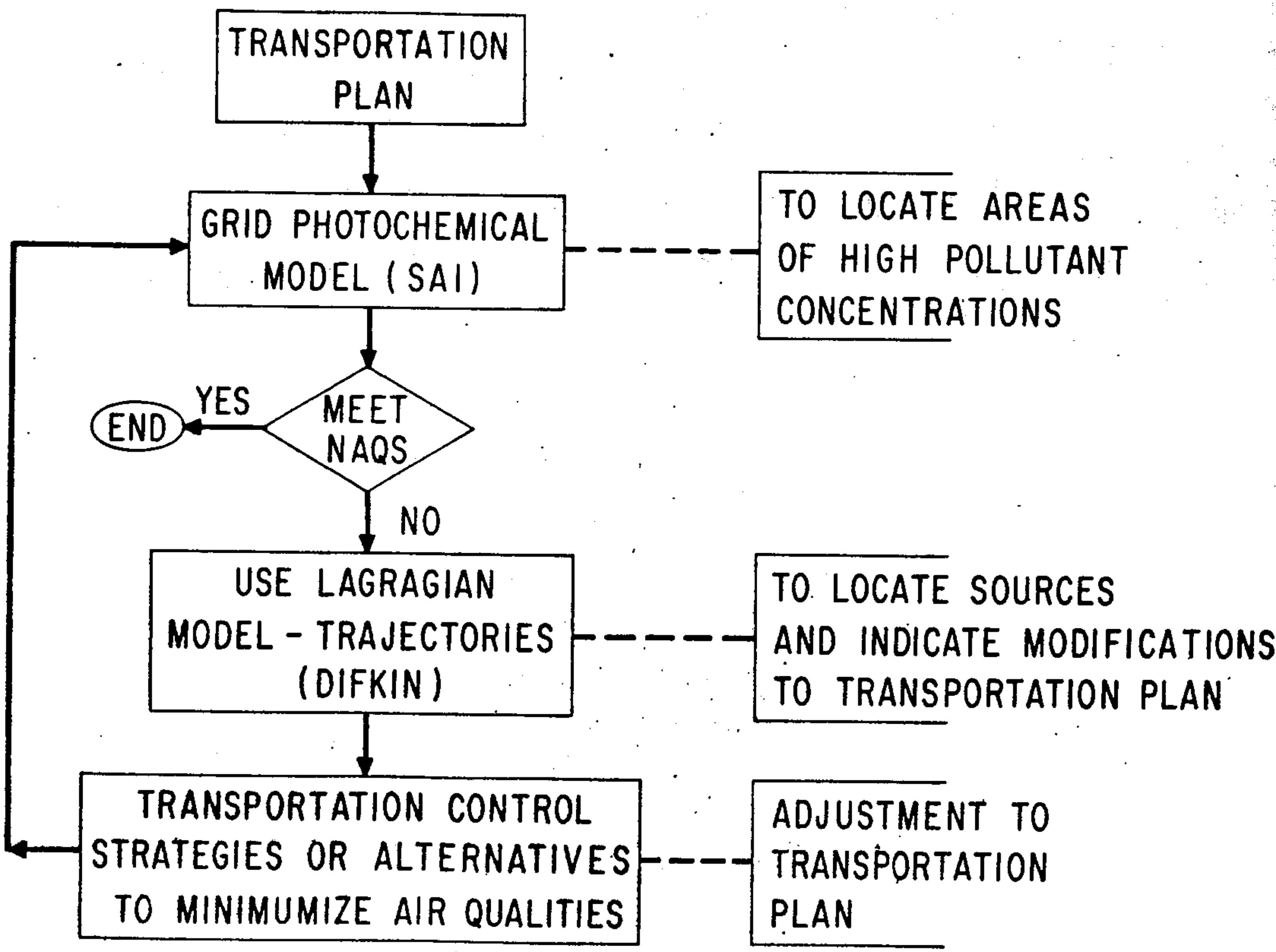


FIGURE 13-22

3. Difficult to validate models unless these localized effects are considered in the model.

4. Need point measurements of air quality which is representative of entire grid area.

5. Poor exposure of meteorological data

   a. Location of APCD stations

   b. Stations with 1 hour averaging times vs instantaneous readings.

B. Consequences of using data that are not representative or based on assumptions of models.

1. Difficult to determine initial concentrations for each grid square with confidence

2. Difficult to determine the wind flow field and trajectories with confidence.

3. No confidence in validation results.

XI. Issues that Must Be Resolved Before Implementing Regional Air Quality Models.

A. Define Study Area and interface of mobile and stationary source inventories for each grid; must use same coordinate system.

B. Boundary Conditions - The location of all terrain features that may alter surface winds and effect transport of pollutants must be changed in the computer programs.

C. Meteorological Data Base - The surface wind flow field, vertical wind shear, diffusion coefficients, radiation intensity, and spatial distribution of surface based and elevated inversions must be described for study area.

D. Air Quality Data Base - The initial concentrations of reactive hydrocarbons, oxides of nitrogen, and carbon monoxide must be specified for the grids if chemical modules are to describe "real world" chemical reactions with any degree of accuracy.

E. Verification program to evaluate models - It has been requested by EPA Region 9 that verification studies be made for each study area.

XII. Caltrans Involvement in Implementing Regional Air Quality Models

A. Design an air and meteorological survey consistent with model assumptions to provide a sufficient aerometric data base.

1. Bag sampling
2. Air quality van(s)
3. Aircraft package
4. Double triangulation theodolite
5. Weather stations
6. Solar radiation
7. Manpower

B. Modified Models for each study area

C. Provide leadership in transportation planning now including environmental inputs. (Action rather than a reaction agency)

XIII. Status of Computer Programs for Regional Modeling

A. Rollback

B. SRI APRAC-1A

C. DIFKIN

D. PES

E. SAI

SECTION 14

REPORTS

I. Levels of Air Quality Reports

A. Paper Study

1. Small projects - less than 1000 VPH$\underline{+}$

2. Use existing data if available

a. Air Quality
b. Meteorology

3. Emphasis Worst/Worst Case

a. Microscale - predict above baseline
b. Mesoscale - tons per day for highway section

4. No monitoring required unless environmentally sensitive area.

B. Complete Air Quality Study

1. Design air and meteorological surveys for microscale and regional area

2. Collect aerometric data

3. Model Validation

a. Microscale
b. Regional

II. Flow Chart for Air Quality Study - See Figure 14-1

A. Planning Phase

1. Project review
2. Request traffic data
3. Historical air and meteorological data
4. Design air and meteorological surveys

B. Field Sampling

1. Short term - critical pollutant season
2. Long term - seasonal variations

C. Data Rediction

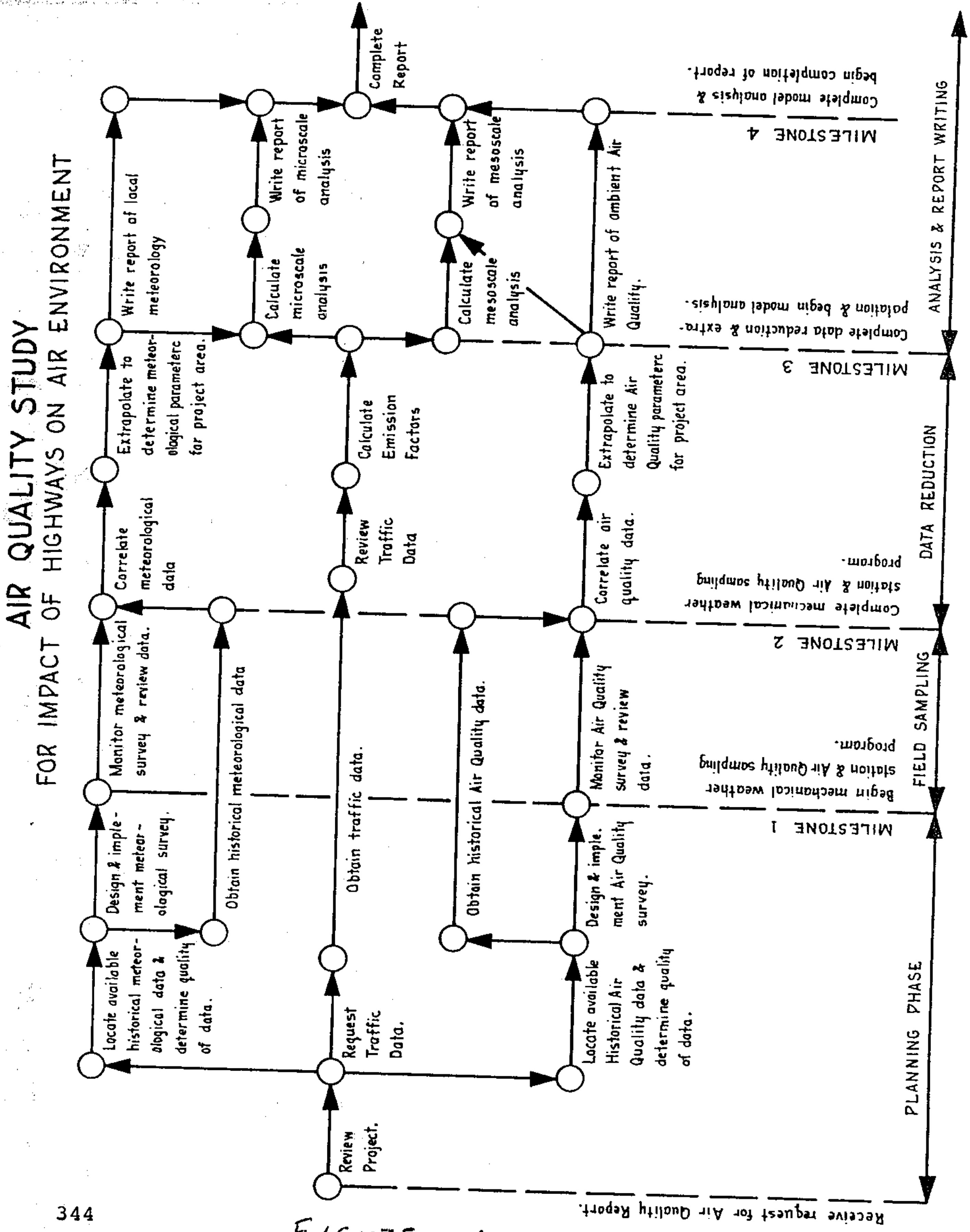
1. Correlate air and metrological data
2. Review traffic data base
3. Analyze surface streamlines and air quality for project and region

D. Analysis and Report Writing

1. Mathematical Analyses and Air Quality Modeling

   a. Microscale
   b. Regional

2. Alternatives
3. Time Periods
4. Meteorological Conditions
5. Report



AIR QUALITY STUDY
FOR IMPACT OF HIGHWAYS ON AIR ENVIRONMENT
Receive request for Air Quality Report.
Review Project.
Request Traffic Data.
Locate available historical meteor-ological data & determine quality of data.
Design & imple-ment meteor-ological survey.
Obtain historical meteorological data
Monitor meteorological survey & review data.
Correlate meteorological data
Extrapolate to determine meteor-ological parameterc for project area.
Write report of local meteorology
Obtain traffic data.
Review Traffic Data
Calculate Emission Factors
Calculate microscale analysis
Write report of microscale analysis
Complete Report
Locate available Historical Air Quality data & determine quality of data.
Design & imple. ment Air Quality survey.
Obtain historical Air Quality data.
Monitor Air Quality survey & review data.
Correlate air quality data.
Extrapolate to determine Air Quality parameterc for project area.
Calculate mesoscale analysis
Write report of mesoscale analysis
Write report of ambient Air Quality.
MILESTONE 1
Begin mechanical weather station & Air Quality sampling program.
MILESTONE 2
Complete mechanical weather station & Air Quality sampling program.
MILESTONE 3
Complete data reduction & extra-polation & begin model analysis.
MILESTONE 4
Complete model analysis & begin completion of report.
PLANNING PHASE
FIELD SAMPLING
DATA REDUCTION
ANALYSIS & REPORT WRITING

FIGURE 14-1

III. Suggested Format for Report

A. Executive, or Summary, Section of Report

1. Acknowledgement
2. Introduction
3. Project Description
4. Summary of Results

    a. Answer basic environmental questions discussed in Section 1

B. Technical Section of Report

5. Traffic Estimates

    a. Transportation model and assumptions
    b. Microscale - VPH
    c. Mesoscale - VMT
    d. Basin - VMT

6. Emission Factors

7. Meteorology

    a. Air Basin
    b. General Climatological Features
    c. Air Pollution Meteorology
    d. Surface Winds and Transport
    e. Surface Atmospheric Stability
    f. Existing Meteorological Sources
    g. Meteorological Field Study
    h. Data Analysis

8. Ambient Air Quality

   a. Historical Air Quality
   b. Sources and Trends of Air quality
   c. Exposure of Existing Sources
   d. On-Site Air Quality Sampling Program
   e. Existing Baseline Pollution Levels

9. Mathematical Analysis

   a. Air Basin - TPD Analysis
   b. Mesoscale - TPD Analysis
   c. Future Ambient Air Quality based on Rollback
   d. Impact Assessment based on Air Quality Modeling

      (1) Predict air quality concentrations
      (2) Microscale
      (3) Mesoscale
      (4) Air Basin

10. Air Quality Standards and State Implementation Plan

11. References

12. Appendices of Data Base

   a. Meteorology
   b. Air Quality
   c. Statistical Analyses
   d. Computer Outputs

13. Glossary of Terms

C. Report Format in Manual

   1. The above format can be used in place of format suggested in the manual or can be used to supplement that approach.

IV. Comments on the Evaluation of Air Quality Reports

A. Project Description and Introduction

1. Define problem and overview

2. Indicate type of highway design, length of project, topography within area, estimated time of completion (ETC).

3. Discuss which pollutants are analyzed and why they were chosen.

4. Discuss type of analysis and define:

   a. Microscale
   b. Mesoscale
   c. Basin

5. Estimates of CO considers "bad" or "typical" day cases.

6. Mention any air quality or meteorological survey and the duration of study.

7. Discuss project coordination with other agencies (local and State).

8. Discuss any particular public concern with project air Quality.

B. Traffic Information

1. State assumptions of traffic estimates for land use.

2. Mention that the traffic estimates are based upon the land use studies made by L.A. County, etc.

Part 3

a. What use can be made of the APCD data for the project? For the entire study area?

b. Is it necessary to design an air quality survey for the study area? Project? If so, where should stations be located and why? Design the survey for CO and O_3. Assume an air quality van can be used to monitor O_3.

6. Discuss Pasquill stability classes A through F and discuss the general weather conditions associated with unstable, neutral and stable conditions.

   Example: Unstable - summer daytime conditions associated with clear skies and light winds

7. For correlation analysis of different wind systems discuss:

   a. response or threshhold wind speeds of the system
   b. exposure
   c. calibration and maintenance
   d. averaging time

8. When using historical data state the number of years available and how many years were used in your analysis.

   a. generally, use a minimum of 5 years of record as recommended by U.S.W.B.

   b. other reasons based on a statistical analysis or recommendations by experts

E. Ambient Air Quality Analysis

1. State all sources near project area.
2. Discuss exposure of APCD stations:

   a. located on main surface streets reflecting local traffic densities

b. local aerodynamic effects
ref: SRI, L.A. Project

c. station sould be 200 to 400 feet away from local sources
ref: Ott, L.A. Project

d. show pictures of improper exposure

3. State that sampling sites for the air quality survey are based on homogeneous land use patterns and sensitive receptors based on the criteria discussed in manual.

4. State why each site was selected as being representative of area, etc.

5. Indicate at what height samples are taken

6. Discuss the sampling train and equipment

7. Show pictures of a typical sampling site.

8. Use historical data to indicate the worst season for pollutants and design your survey accordingly.

9. Discuss why you sampled during a specified period, seasons, etc.

10. If using APCD data to estimate representative worst case baseline air quality conditions generally use last two years of data because:

    a. major development in area
    b. more vehicles with emission control devices
    c. APCD station moved prior to analysis
    d. change of instrumentation

11. Discuss the calibration of CO analyzer, model number, etc., and location where the bags are analyzed.

12. When making correlations at APCD stations, discuss how often they calibrate their instrumentation.

13. Predict future background levels for CO if applicable.

14. Discuss the transport of pollutants

F. Mathematical Modeling or Analysis

1. Define microscale and mesoscale analysis
2. Discuss model relationship to:

    a. traffic volumes
    b. emission factors
    c. meteorology
    d. type of highway design

3. List the assumptions for microscale and regional air quality models.

4. Mention microscale model is recommended by EPA as "an approach" to estimate CO concentration for a highway line source.

Reference: Dr. Ralph Sklarew, "Air Quality Environmental Impact Statements for Highway Projects", EPA Training Class, September 1972.

5. Estimates are above baseline levels.

6. Discuss the assumption and meaning of "worst" and "typical" cases.

7. State the inputs for the "most probable" and "worst" meteorological conditions where applicable.

8. Discuss the approach used to predict photochemical pollutants (O_3, etc.) and quality and interpretation of the results.

G. State Implementation Plan

1. Discuss briefly the objective goals of the "State Implementation Plan".

2. Show how highway project fits into this plan (be specific).

H. General Comments

1. State all references

2. Include a glossary of terms.

3. Avoid the statement "without the freeway traffic will increase". Say "studies made by __________ indicate that whether the freeway is built or not, the traffic will increase".

4. In the air quality report, answer the six basic questions discussed on Pages 4 and 5 in "A Method for Analyzing and Reporting Highway Impact on Air Quality".

V. Methods of Presenting Data

A. Tabular

B. Graphically - See Figures 14-2 through 14-4

VI. Recommended Air Quality Reports for Review made by Caltrans Transportation Districts:

A. Air Quality Report for the Route 118 Freeway Proposal From Balboa Boulevard in Granada Hills to De Soto Avenue in Chatsworth, Transportation District 07, July 1974.

B. Air Quality Report El Segundo - Norwalk Freeway, 07-LA-1/105, Transportation District 07.

C. Air Quality Report Foothill Freeway 07-LA-210, Transportation District 07.

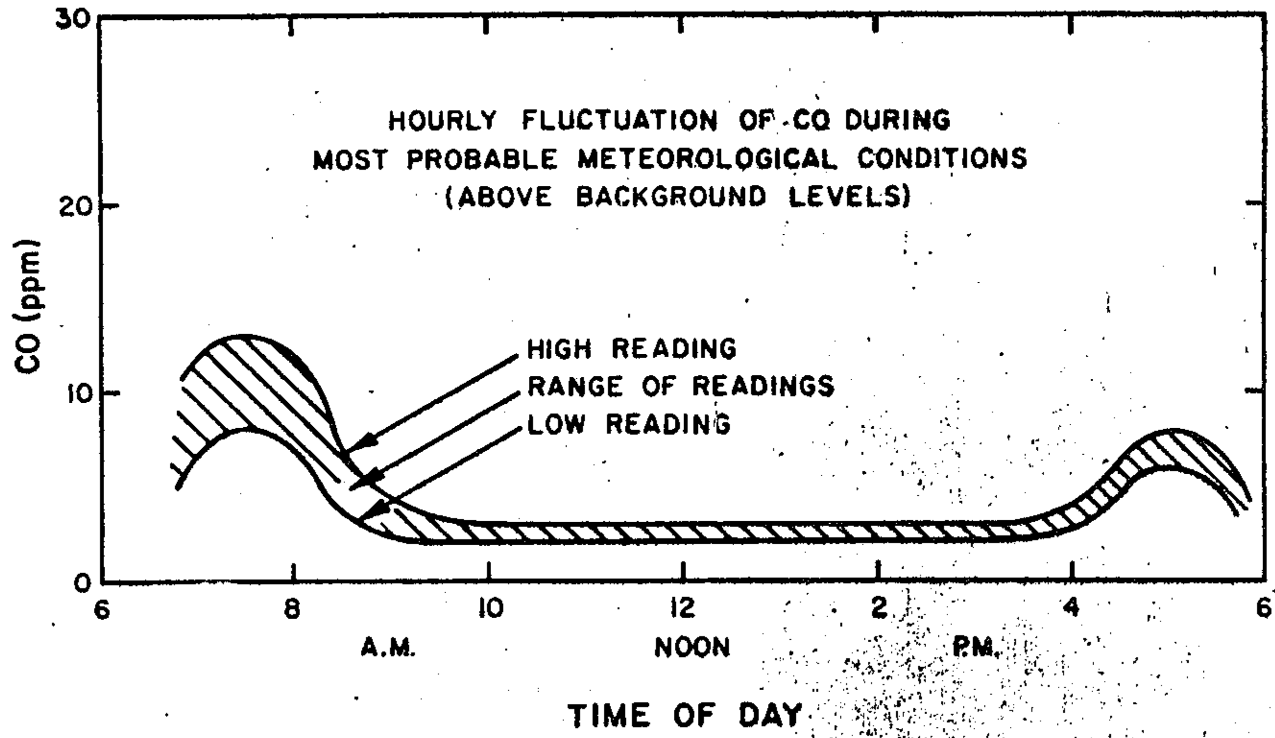
D. Air Quality Report Route 252 in San Diego From Route 5/15 Separation to 0.4 mile W. of Route 805, Transportation District 11.

E. Air Quality Report on Route 101 Santa Barbara County, Transportation District 05.

F. Air Quality Report in Kern County from 1.6 Miles East of Route 14 to 1.3 Miles East of California City Boulevard Kern County, Transportation District 09.

G. Air Quality Analyses Route 17, 80, and 93 in Richmond Area and Impact Study, Transportation District 04.

ESTIMATED 1975 SUMMER CONCENTRATIONS OF CARBON MONOXIDE AT NORBRIDGE SCHOOL WITH PROPOSED NEW FREEWAY



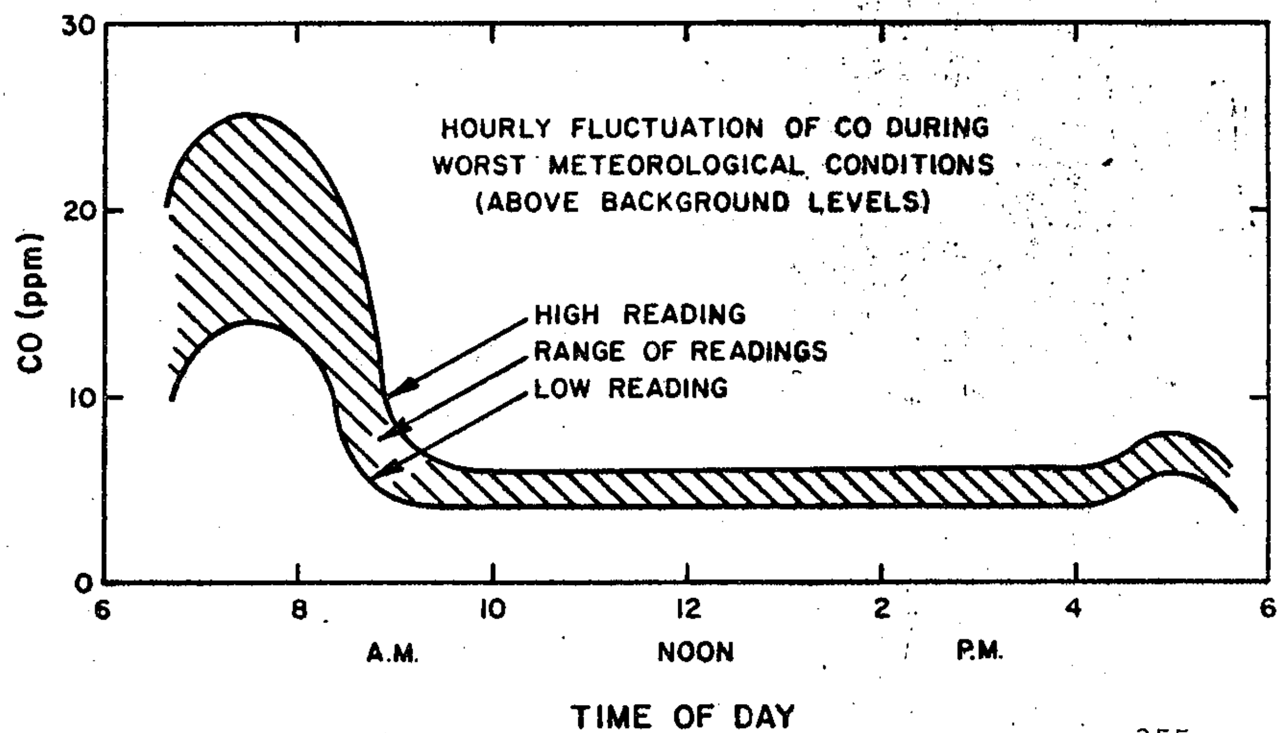
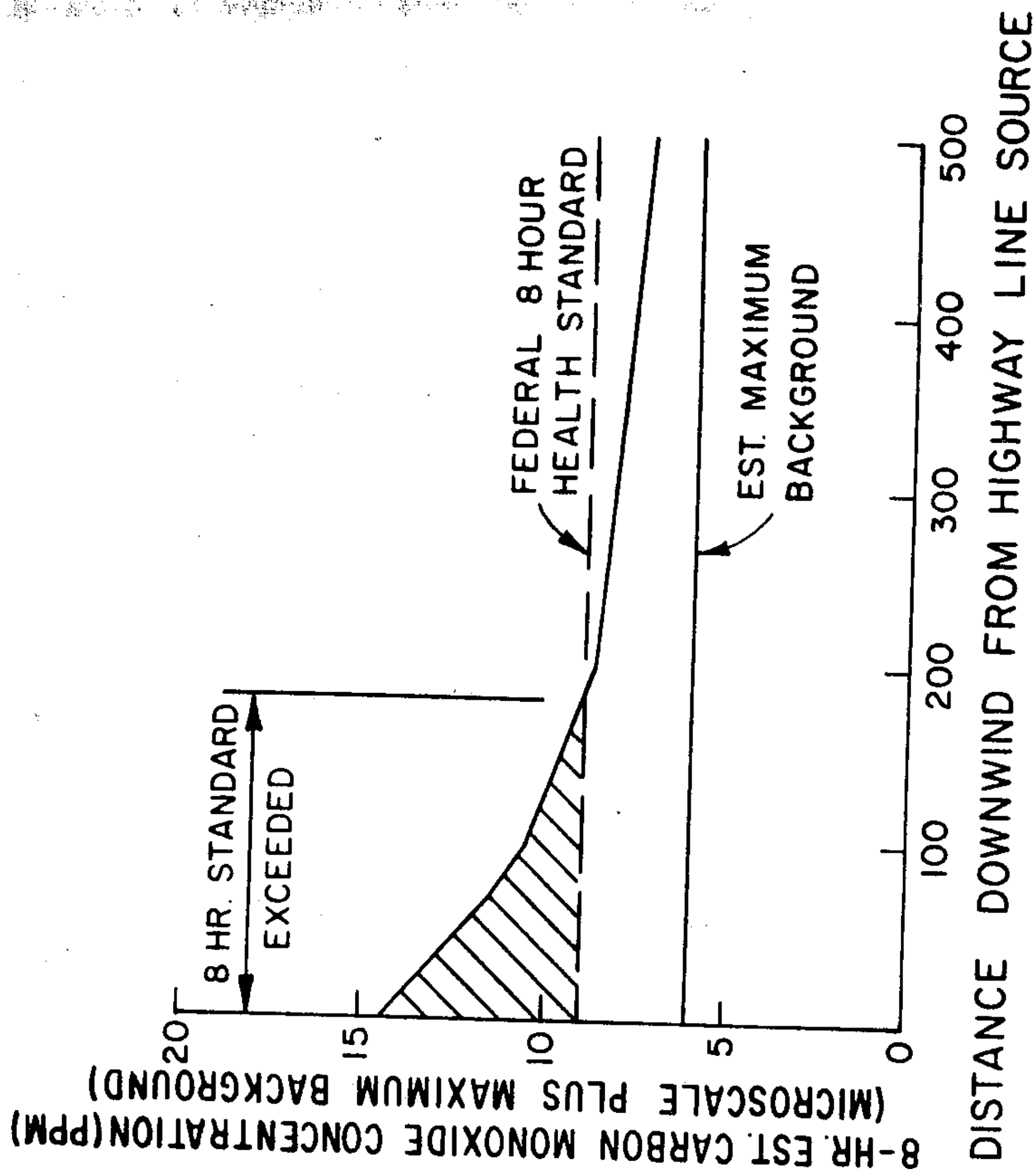


FIGURE 14-2



8 HR. STANDARD
EXCEEDED
FEDERAL 8 HOUR
HEALTH STANDARD
EST. MAXIMUM
BACKGROUND
20
15
10
5
0
100
200
300
400
500
8-HR. EST. CARBON MONOXIDE CONCENTRATION (PPM)
(MICROSCALE PLUS MAXIMUM BACKGROUND)
DISTANCE DOWNWIND FROM HIGHWAY LINE SOURCE

FIGURE 14-3

ESTIMATED TOTAL TRAFFIC LOAD FOR
CARBON MONOXIDE
IN THE OAKLAND-HAYWARD AREA (ZONE I)

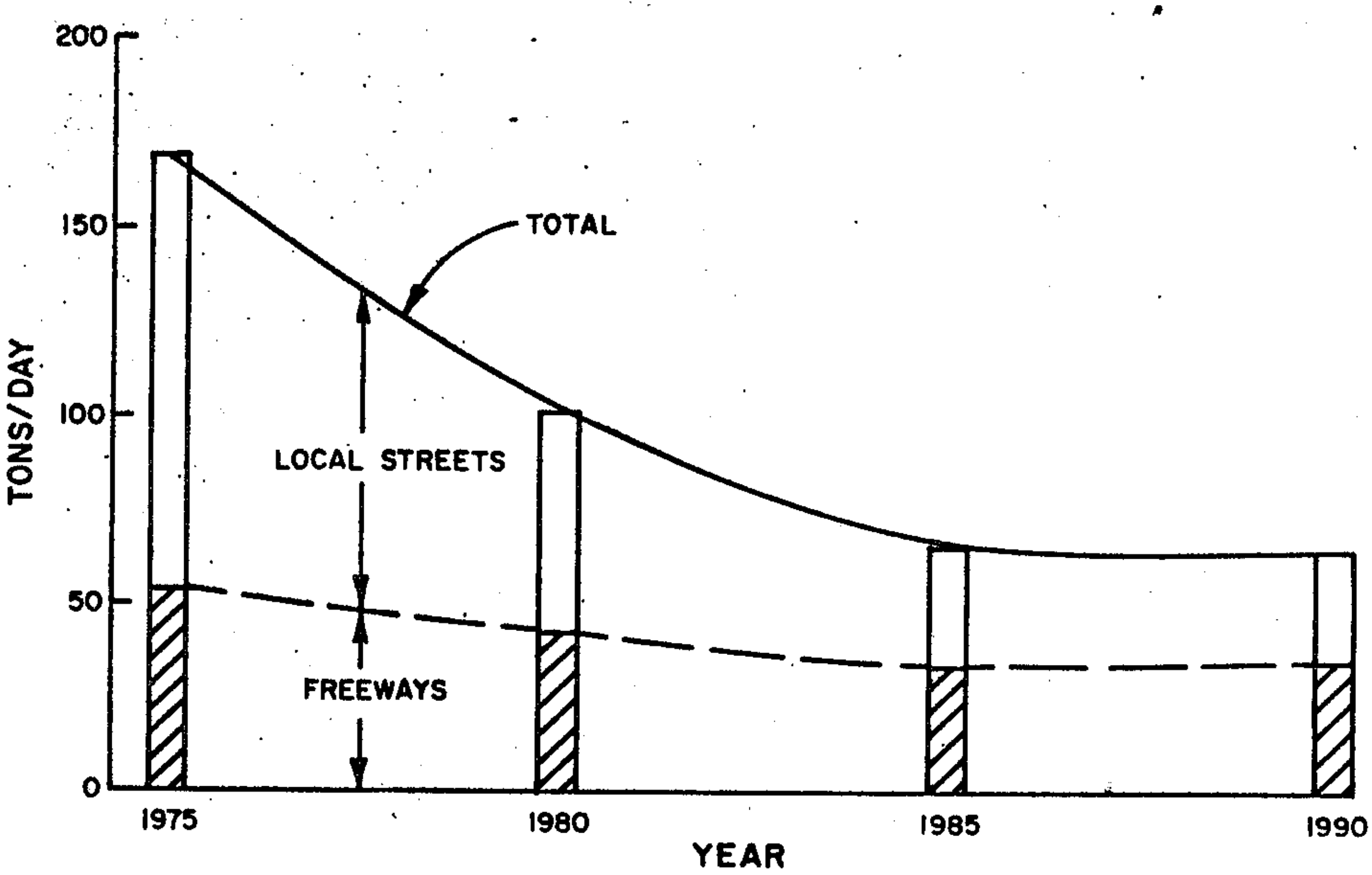


FIGURE 14-4

APPENDIX A

REFERENCE BOOKS AND PUBLICATIONS

The following publications are the references used to develop this set of lecture notes:

1. Beaton, J. L., Skog, J. B., Shirley, E. C. and Ranzieri, A. J.

   A. "Meteorology and Its Influence on the Dispersion of Pollutants from Highway Line Sources".

   B. "Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality".

   C. "Traffic Information Requirements for Estimates of Highway Impact on Air Quality:.

   D. "Mathematical Approach to Estimating Highway Impact on Air Quality"

   E. "Appendix to Modeling".

   F. "Analysis of Ambient Air Quality for Highway Projects"

   G. "A Method for Analyzing and Reporting Highway Impact on Air Quality"

   H. "Synthesis of Information on Highway Transportation and Air Quality"

2. Kerri, K., Ranzieri, A. J., Torguson, E., "Applications of Regression Analysis to Environmental Problems for Highway Projects", January 1973.

3. Ranzieri, A. J., and Bemis, G. R., "Applications of Statistics in Analyzing Aerometric Data for Transportation Systems", October 1974.

4. Pinkerman, K. O., Ranzieri, A. J. and Shirley, E. C., "Design and Development of a Mobile Air Quality Van for Highway Environmental Impact Studies", September 1974.

5. Peter, R. R. and Pinkerman, K. O., "Method for Analysis of Total Particulate and Lead Concentration in Ambient Air", July 1974.

6. Peter, R. R. and Pinkerman, K. O., "Method of Calibration of the High-Volume Sampler Flow Recorder", July 1974.

7. Ranzieri, A. J. unpublished report "Carbon Monoxide Emission Factor at Idle", January 1973.

8. Ranzieri, A. J. Lecture Notes for EPA Training Course on "Advance State of Art of Line Source Diffusion Modeling", November 1974.

9. Ranzieri, A. J., Lecture Notes for EPA Modeling Conference "Applications of Regional Air Quality Models for Transportation Impact Studies", November 1974.

10. Ranzieri, A. J., Lecture Notes for course at California State University, Sacramento, "The Use of Richardson Number in Atmospheric Diffusion Modeling", May 1973.

11. Batham, M. D., Ames, D. J. and Ranzieri, A. J., "A Feasibility Study of Bag Sampling For Hydrocarbon Analysis", December 1974.

12. Batham, M. D., "Emission Factor Manual Modification No. 2, 3 and 4 and Computer Program", May 1973, August 1974, and September 1974.

13. Ranzieri, A. J., and Bemis, G. R., "Modification to Line Source Diffusion Model for Cut Sections", September 1973.

14. Allen, P. D., Crews, W. B. and Ranzieri, A. J., Draft Report "A DIFKIN Sensivity Analysis for Transportation Air Quality Studies", January 1975.

15. Shirley, E. C., Ranzieri, A. J., Pinkerman, K. O. and Bemis, G. R., Research Progress Reports Numbers 1, 2, 3 and 4, "Air Pollution and Roadway Location, Design and Operation", September 1971, June 1972, September 1973, and January 1975.

16. Roth, P. M., et al, "An Introduction to the SAI Airshed Model and its Usage", Systems Applications Inc., San Rafael, California, June 1974.

17. National Highway Institute Training Manual, "Highway Air Pollution".

HOMEWORK PROBLEMS

HOMEWORK PROBLEM NO. 1

Given:

The following traffic data is for an urban area with and without a proposed freeway. Assume a 5% HDV mix on the freeway and urban streets. The estimated time of completion of the proposed freeway is 1980.

Find:

From the information given estimate the increase or decrease in the CO pollutant load (tons/day) within the impact area if the proposed freeway is built.

Traffic Data:

Daily Vehicle Mileage (DVM) on
urban streets without freeway . . . . 460,000 mi/day

Daily Vehicle Mileage (DVM) on
freeway in urban area . . . . 260,000 mi/day

Daily Vehicle Mileage (DVM) on
urban streets with freeway . . . . 300,000 mi/day

Average route speed on freeway	50 mph
Average route speed on urban streets	20 mph
Emission factor on freeway	8.4 gm/mi
Emission factor on urban streets	18.2 gm/mi

HOMEWORK PROBLEM NO. 2

Given:

The same traffic data as given in Homework Problem No. 1 except that the estimated time of completion of the freeway is 1985.

Find:

Estimate the increase or decrease of the CO pollutant load (tons/day) within the impact area if the proposed freeway is built.

Emission Factors 1985	Freeways	=	5.5 gm/mi
Emission Factors 1985	Urban Streets	=	12.0 gm/mi.

HOMEWORK PROBLEM NO. 3

Given:

An 6 lane highway is planned built to replace an existing 2-lane highway as shown in Figure 1. The highway is planned between points A and B. A small rural community is located near the middle of the valley. All of the alternate routes will provide access roads to and from the local community.

Find:

From the information given, answer the following:

1. Draw the general diurnal surface wind stream lines for the impact area under possible inversion characteristics.

2. Discuss the general dispersion and transport of pollutants for each alternate route.

3. What is the best alternate route to minimize the impact of the highway on the air environment within the highway corridor and valley? Which alternate route is the worst?

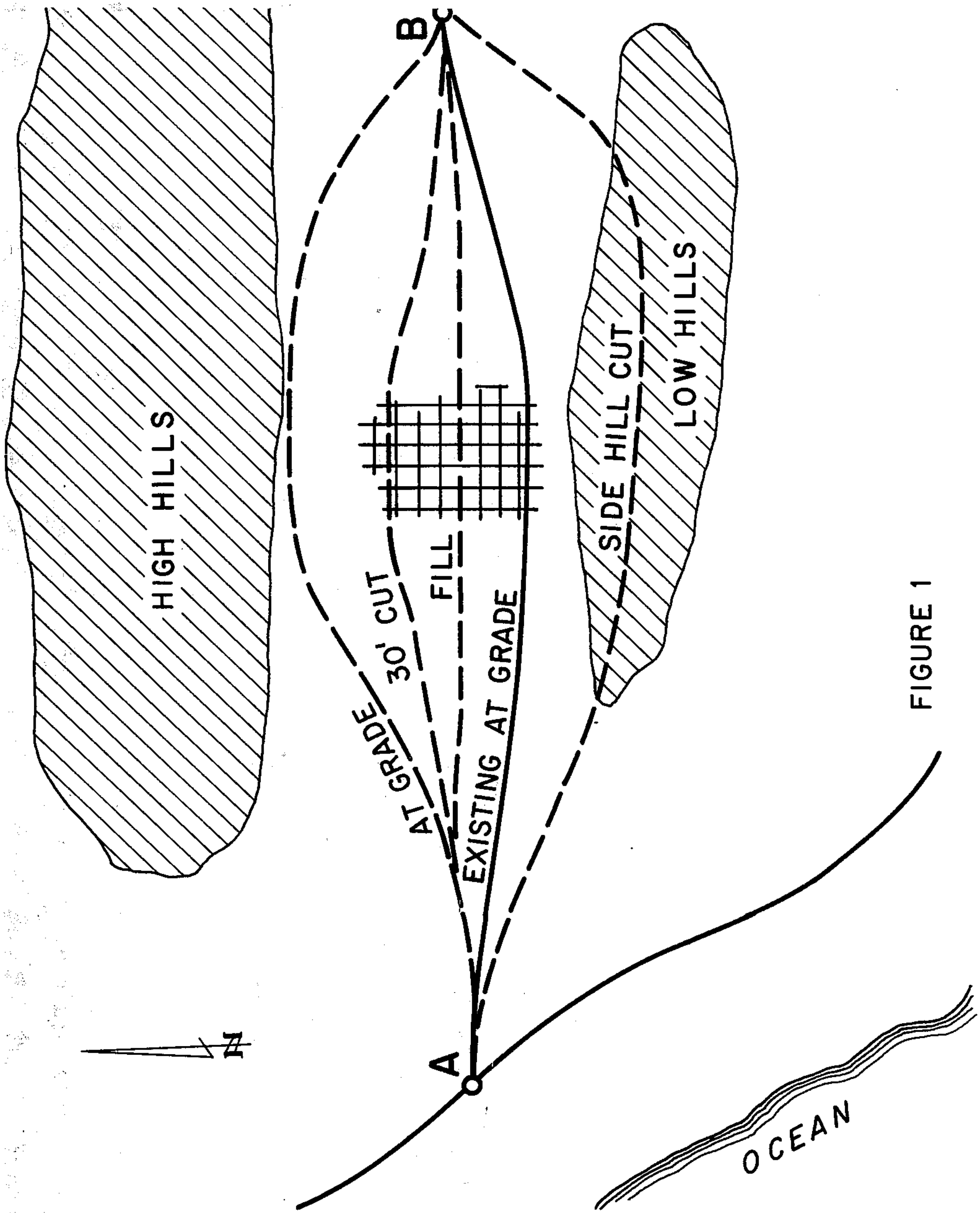

B
A
HIGH HILLS
LOW HILLS
SIDE HILL CUT
30' CUT
FILL
AT GRADE
EXISTING AT GRADE
OCEAN
N

FIGURE 1

HOMEWORK PROBLEM NO. 4

Given:

A highway is planned between Points A and B shown in Figure 1. The major portion of the highway is to be located within the canyon. There are two meteorological sources that record wind speed and direction. They are at the airport located near the ocean and an air pollution district monitoring station located within the Skog Valley. Both meteorological stations have good exposure for the wind instrumentation.

Problem:

From the information given answer the following:

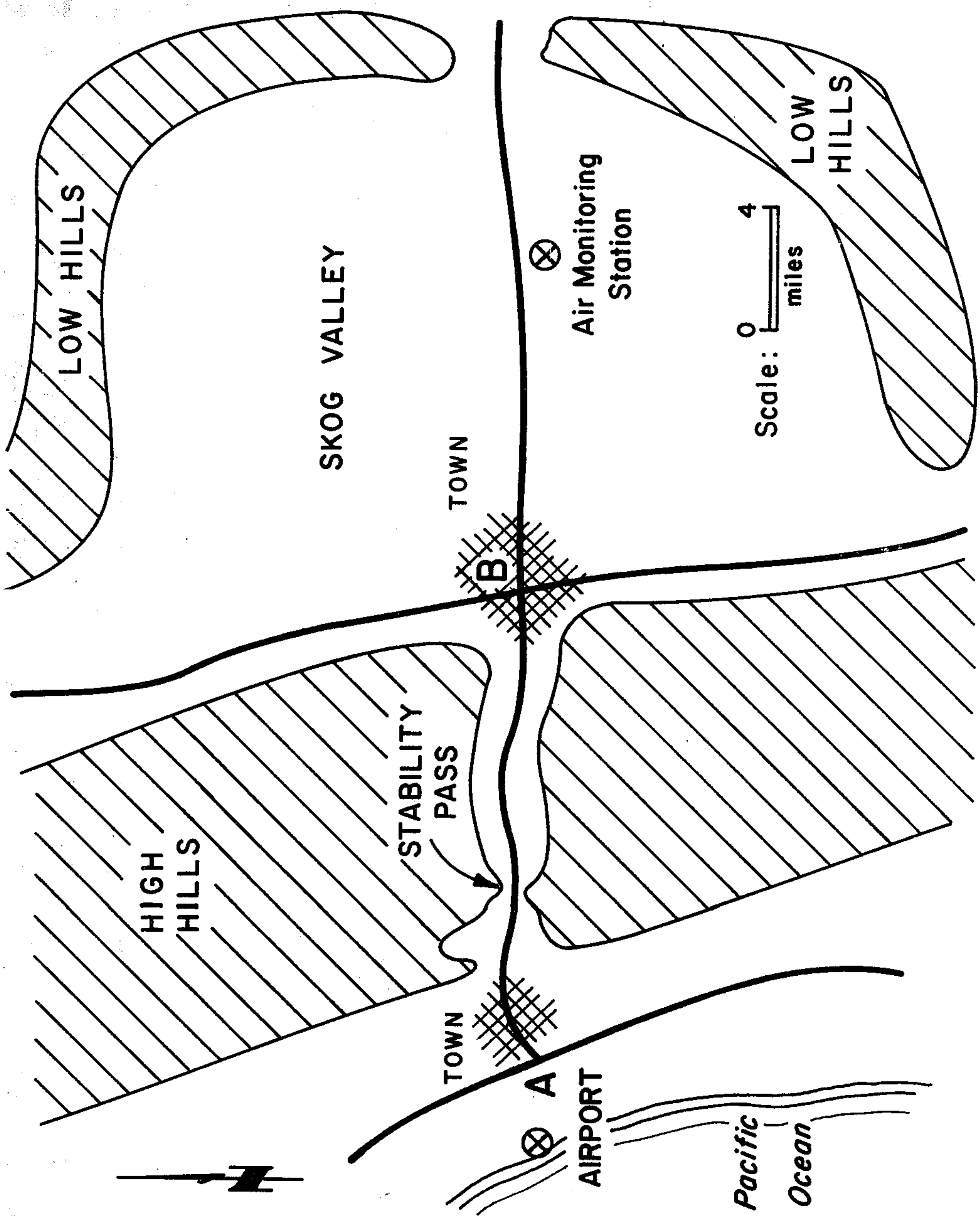
1. Sketch the general diurnal surface wind streamlines for low and high based inversions.

2. Are the wind data taken at the airport and/or the air monitoring station representative for the sea breeze regime for the project? Drainage wind? Explain.

3. Can the data at the airport and air monitoring station be used for portions of the highway?

4. Is a meteorological survey required for the project area? If so, how many mechanical weather stations should be used and where should they be placed?

   What type of exposure of the wind system is required? How long should the survey last?


LOW HILLS
LOW HILLS
SKOG VALLEY
Air Monitoring Station
Scale: 0 4 miles
TOWN
B
HIGH HILLS
STABILITY PASS
TOWN
A
AIRPORT
Pacific Ocean
N

HOMEWORK PROBLEM NO. 5

AIR QUALITY SURVEY

Given:

A proposed freeway (ABCD) would connect the coastal State highway with Freeway C and would be located in an urban area. The estimated ADT for 1980, the completion date, is 60,000. It is anticipated by planners that this additional travel will result from future growth in the eastern part of the community which will have direct access to the airport. Because of city land use restrictions, the portion of freeway traversing the light industrial area is at-grade. The major portion of the Freeway C-D is in a 24-foot cut to reduce environmental problems related to noise. Located within the south-western part of the impact area is heavy industrialization consisting of oil refineries and chemical plants. There is an air pollution control district monitoring station (APCD) located near the interchange in the State highway route and the surface arterial street as shown in Figure 1. The air intake for the APCD station is located at a building approximately 50 feet from the interchange area. The only source of meteorological information with proper sensor exposure is at the airport. There are four schools within the area. The geographical location of these schools with respect to the freeways and surface streets is as follows:

School 1

300 feet south of proposed freeway and
3 miles west of Freeway B.

School 2

2 miles south of proposed freeway and
3 miles east of Freeway B.

School 3

250 feet north of proposed freeway and
5 miles east of Freeway B.

School 4

500 feet east of interchange and 200 feet
south of State highway.

The total length of the project is 17 miles.

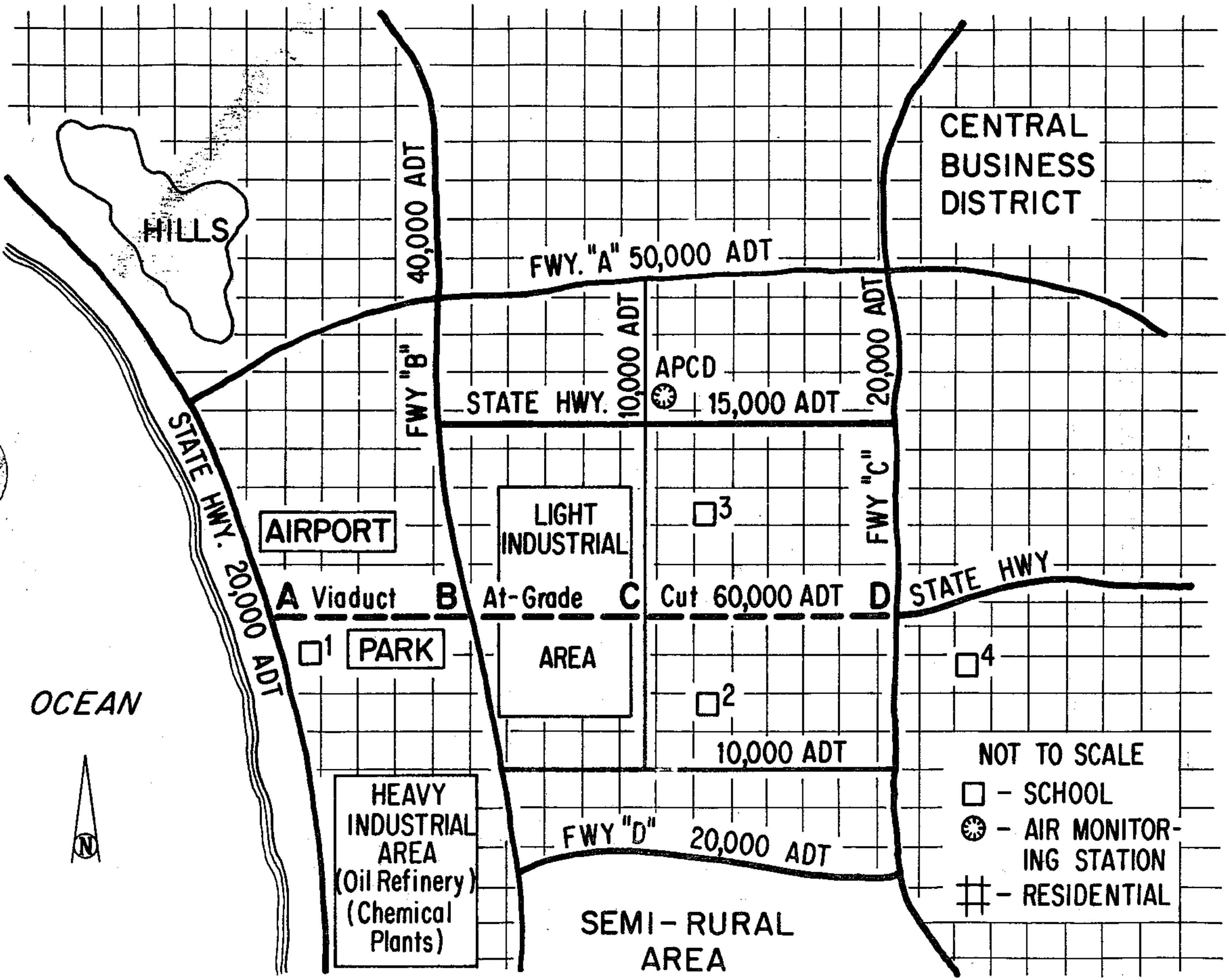
Problem:

1. Is the APCD station representative of the proposed highway route? Explain.

2. Are there sufficient meteorological data available to characterize the surface streamlines of the project area? Explain.

3. If it is determined in (1) above that the APCD station is not representative of the project area, design an air quality survey for CO. Assume that a maximum of four bag samplers are available (if necessary) to determine the existing air quality of the proposed route.

   Design an air quality survey. Use an air quality van for O_3.


CENTRAL BUSINESS DISTRICT
FWY. "A" 50,000 ADT
40,000 ADT
FWY "B"
HILLS
20,000 ADT
10,000 ADT
APCD
STATE HWY.
15,000 ADT
FWY "C"
LIGHT INDUSTRIAL AREA
AIRPORT
STATE HWY
A Viaduct B At-Grade C Cut 60,000 ADT D
PARK
1
2
3
4
STATE HWY. 20,000 ADT
OCEAN
10,000 ADT
HEAVY INDUSTRIAL AREA (Oil Refinery) (Chemical Plants)
FWY "D" 20,000 ADT
SEMI-RURAL AREA
N
NOT TO SCALE
- SCHOOL
- AIR MONITORING STATION
- RESIDENTIAL

HOMEWORK PROBLEM No. 6

TRAFFIC, AIR AND METEOROLOGICAL SURVEYS

Part I

The existing highway is two lanes located as shown in Figure 1. It is proposed to relocate the existing facilities and have a 4 lane freeway to relieve traffic congestion and accommodate future growth.

Local environmental groups are concerned that the proposed re-alignment and 4 lane freeway will act as a catalyst to promote future accelerated growth within the surrounding area. Their arguments are that the area east of town is presently zoned for agricultural use but developers have been trying to convince the County Planning Commission to rezone the area for residential use.

The environmentalists contend that, with all of the potential growth, the area will have a problem with air quality. They argue that the town is generally surrounded by hills and located in a "bowl" and along with the frequent temperature inversions may be a "suicide box" for air pollution. They also believe that the future traffic forecasts by the Highway Department are not realistic because the energy crisis has increased gasoline costs and reduced roadway use. The traffic estimates are shown in Figure 1 and are for the time when the area is fully developed in 1995. The environmentalists also contend that the traffic in future years will not get appreciably worse because of the limited availability of gasoline. They also contend that there has been a recent reduction of tourists and recreational traffic along with the increased ridership in the local buses.

However, the environmental groups are concerned about alleviating the traffic congestion and reducing air pollution with the minimal impact on growth and energy requirements. In order to achieve this goal they advocate that the State should be concerned with moving "people and not vehicles". They propose an improved bus system with increased service.

a. To assess the impact of the proposed transportation system on the air environment, discuss the possible alternatives and what traffic information is required. What type of an analysis should be made to assess the energy requirement for each alternative?

Part 2

Within Skogsville there is a continuous air monitoring station (CAMP) operated by the local air pollution control district. The CAMP station is located in a building within the downtown area on the third floor. On top of the building is a wind system. It is located near the center of the building about 10 feet above the roof. The street where the air sensor is located runs in an east-west direction. The CAMP station monitors CO, HC, NOx, NO, NO_2, O_3 and particulates. Figure 2 illustrates the location of the CAMP station.

Problem:

a. Draw the diurnal streamlines for the study area for drainage winds and high and low based elevated inversions. Assume low point of valley is in NW corner of study area.

b. What use can be made of the historical meterological data?

c. Is a meterological survey required? If so, design the survey.

Part 3

a. What use can be made of the APCD data for the project? For the entire study area?

b. Is it necessary to design an air quality survey for the study area? Project? If so, where should stations be located and why? Design the survey for CO and O_3. Assume an air quality van can be used to monitor O_3.

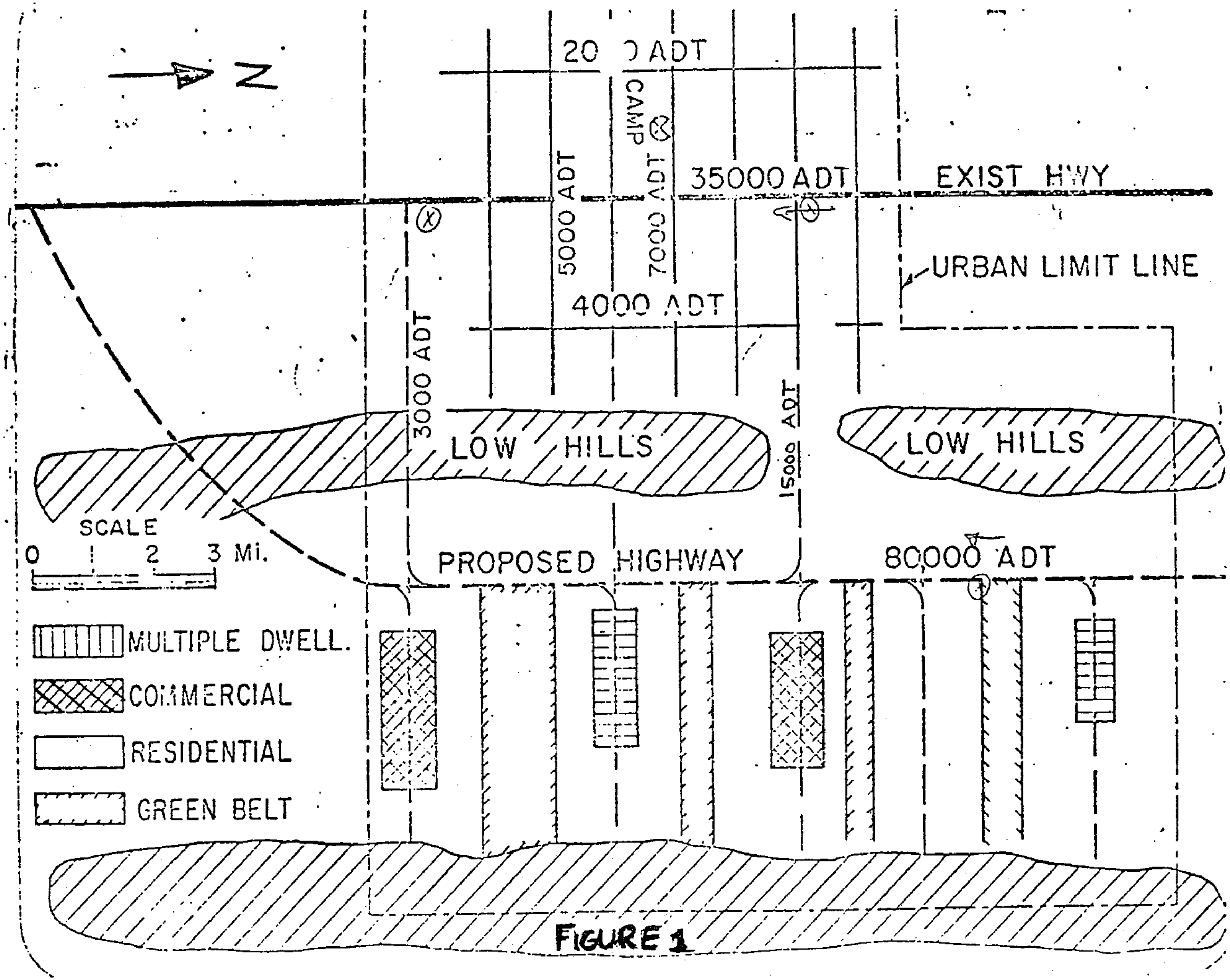

N
20 ⊃ ADT
CAMP
35000 ADT
EXIST HWY
5000 ADT
7000 ADT
URBAN LIMIT LINE
4000 ADT
3000 ADT
LOW HILLS
15000 ADT
LOW HILLS
SCALE
0 1 2 3 Mi.
PROPOSED HIGHWAY
80,000 ADT
MULTIPLE DWELL.
COMMERCIAL
RESIDENTIAL
GREEN BELT

FIGURE 1

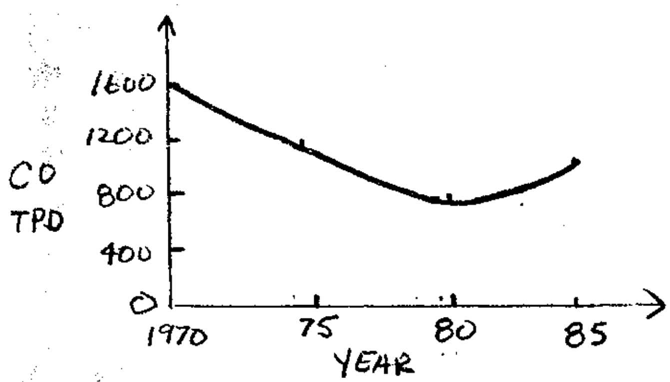
HOMEWORK PROBLEM NO. 7

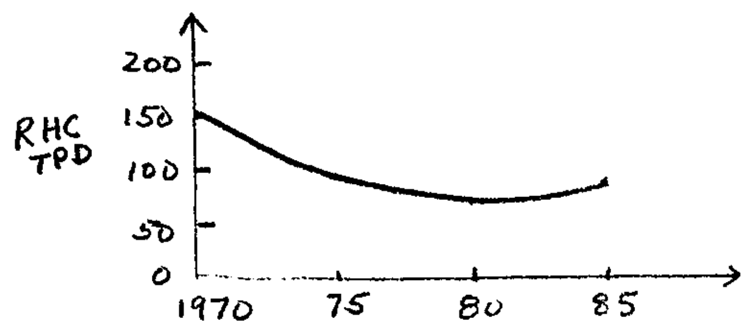
Given:

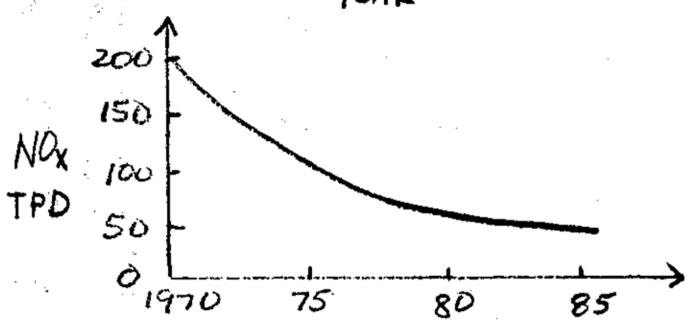
An air quality survey was made for a highway project and the highest measured hourly concentrations were as follows:

$CO = 45$ ppm
$NO_2 = 0.30$ ppm
$O_3 = 0.42$ ppm

The survey was made during the calendar year 1974. The emission inventories for mobile and stationary sources for the mesoscale area are shown in the following graphs.







Find:

Predict the air quality concentrations of CO, NO_2 and O_3 for the future years of 1980 and 1985. What are the limitations and weakness of the rollback approach in predicting future air quality? What effect does the baseline year of air quality have on future predictions using rollback?

IMPACT OF TRANSPORTATION SYSTEMS ON THE AIR ENVIRONMENT

Take Home Exam (Open Book)

True or False

Place a T or an F to the left of the statement number depending upon whether the statement is True or False.

_____ 1. Decrease of wind speed in urban areas is primarily due to the increase in the size of the roughness elements.

_____ 2. Meteorological information on many different scales must be considered with respect to site selection.

_____ 3. Wind speeds less than 3 mph are of particular concern in air pollution meteorology, yet they are difficult to measure with most existing cup anemometers since their starting threshhold is near 3 mph.

_____ 4. The downslope and downvalley winds are usually less frequent and slower than the upslope and upvalley winds due to the increased friction between the ground and the dense air.

_____ 5. In terms of "air pollution" the highway corridor extends both in the upwind and downwind directions to the point where the pollutant concentrations generated by the traffic on the highway are dispersed to the ambient levels.

_____ 6. The California Line Source Diffusion Model (CALINE2) estimates air pollution levels on and within the highway corridor. Estimates above baseline are made using the traffic on the highway as the source.

_____ 7. When the winds are parallel to the highway alignment, the buildup of pollution levels in the downwind direction within the mechanical mixing cell is theoretically greater for Stability A than for Stability F. (CALINE2)

_____ 8. A highway located on an elevated section theoretically reduces the ground level concentrations as compared to an at grade section.

_____ 9. CALINE2 is a photochemical model.

_____ 10. CALINE2 can estimate ozone concentrations.

_____ 11. CALINE2 can estimate the concentrations of HC and NO_x for all meteorological conditions provided emission factors are available.

_____ 12. The "urban heat island effect" of cities can enhance the dispersion of pollutants compared to a rural environment.

_____ 13. In designing meteorological surveys, it is desirable to use hand-held wind systems to assist in determining the exact location for the mechanical weather station.

_____ 14. In general, wind systems located on top of buildings will have proper exposure to measure surface winds.

_____ 15. Local aerodynamic effects of streets can cause a change in the horizontal concentration gradient from one side of the street to the other.

_____ 16. A highway located in a cut section with wind parallel to the alignment tends to restrict the dispersion of pollutants horizontally.

_____ 17. In statistical analyses of air pollution data the meteorological conditions during data collection should be similar for the data being analyzed.

_____ 18. CALINE2 has been statistically validated with field measurements for all types of meteorological conditions.

_____ 19. The Richardson Number gives a comparative measure of atmospheric turbulence.

_____ 20. Regional Gaussian air quality models are applicable for areas where terrain effects alter surface winds.

Multiple Choice

There is one correct answer. Circle the letter designating the correct answer.

23. The mechanical mixing cell on a highway is caused by:

    a. wind flow over the highway
    b. wind shear
    c. motion of moving vehicles

24. The approximate height of the mechanical mixing cell is:

    a. the height of the vehicle
    b. twice the height of the vehicle
    c. three times the height of the vehicle
    d. none of these

25. If a highway line source (at-grade) is under the influence of a surface based inversion, the ground level concentration might be expected to be:

    a. high
    b. low
    c. no effect

27. When compiling meteorological data for prevailing wind direction and speed to be used in the mathematical model, the best time period to use in the analysis is:

a. During changes in the daily and seasonal traffic volumes
b. daylight hours (9 a.m. - 3 p.m.)
c. 4 p.m. - 6 p.m.
d. peak traffic hours

28. In CALINE2, CO is used primarily as a tracer gas because it is:

a. chemically reactive gas
b. is a constituent for photochemical smog
c. is a relatively inert gas in the formation of smog

28. In general, the ambient air quality data measured at APCD stations is representative of a proposed highway route located how far away?

a. 100 feet
b. 500 feet
c. 1 mile
d. none of these

29. The most probable surface stability class for the atmosphere on an early January morning with clear skies and light winds is

a. A
b. C
c. D
d. F

30. The concentration of CO is 0.01 g/m^3. Convert this to ppm. Molecular weight CO = 28.

a. 9
b. 12
c. 15
d. 20

31. The peak traffic hours are from 4 p.m. - 6 p.m. On a clear July afternoon with light winds, what is the most probable surface stability class at this time?

a. A
b. D
c. E.
d. F

32. Same conditions as in question 32, except that the wind speed is 15 mph. What is the most probable surface stability class?

a. A
b. D
c. E
d. F

33. The highest ratio of peak to mean CO concentration is observed under:

a. unstable conditions
b. neutral conditions
c. stable conditions

34. Highest concentrations <u>within</u> the plume for an elevated highway source are with:

a. fumigation conditions
b. trapping conditions
c. lofting
d. fanning
e. strong lapse conditions
f. weak lapse conditions

35. The two primary factors which tend to increase air pollution concentrations are:

a. light winds and fog
b. cloud cover and light winds
c. stable atmosphere and light winds
d. stable atmosphere and fog

36. The temperature at 254 feet above ground minus the temperature at 6 feet is +1.3°F. The lapse rate is:

a. superadiabatic
b. adiabiatic
c. subadiabatic
d. isothermal
e. inversion

37. Thermal instability is most extreme during:

a. nighttime, clear skies, light winds
b. daytime, clear skies, light winds
c. nighttime, cloudy skies, high winds
d. daytime, cloudy skies, light winds
e. daytime, cloudy skies, high winds

38. Highest ground level concentrations near an elevated source occur with:

a. ground based inversion
b. unstable conditions
c. isothermal conditions
d. fumigation condition
e. none of the above

39. What is the value for σz at a distance of 0.20 km for a line source for stability class A?

a. 12 m
b. 9.5 m
c. 7 m
d. 100 m
e. none of these

40. The temperature at 105 feet is 64.0°F and the temperature at 10 feet is 64.3°F. The average lapse rate between these two heights is:

a. superadiabatic
b. adiabatic
c. subadiabatic
d. isothermal
e. inversion

41. The minimum concentration at ground level downwind of an at grade source is during:

a. superadiabatic conditions
b. adiabatic conditions
c. subadiabatic conditions
d. isothermal conditions
e. inversion conditions

42. The National Climatic Center (NCC) is located in:

a. Washington, D. C.
b. New Orleans, LA
c. Kansas City, Kansas
d. Asheville, North Carolina

43. Which of the following pairs of parameters is the most important from a meteorological point of view when considering photochemical reactions in the atmosphere:

a. very high and very low temperatures
b. low wind speed and constant direction
c. precipitation and fog
d. relative humidity and percent possible sunshine

44. For a looping plume, the Pasquill Stability Class is:

a. Stability C-D
b. Stability A-B
c. Stability E-F
d. Stability A-B
e. None of these

45. For an air quality survey, the minimum distance separating CO air sensors and localized sources is:

a. 0 - 100 ft.
b. 200 - 400 ft.
c. 600 - 800 ft.
d. None of these

46. In general, the O_3 concentrations are the highest during the:

a. summer and fall
b. summer and winter
c. winter and spring

47. In general, the highest daily O_3 concentrations occur in

a. early morning
b. midday
c. evening

48. In general, the maximum CO concentrations occur in:

a. winter
b. spring
c. summer
d. fall

49. The transport of pollutants from one city to another is most likely to occur with:

a. light winds, surface based inversion
b. strong winds, surface based inversion
c. light winds, elevated inversion
d. strong winds, elevated inversion

50. For a "short term" air quality survey for CO, it is most important to obtain air samples for:

a. winter
b. spring
c. summer
d. fall
e. All of these

51. The initial vertical dispersion used in CALINE2 for turbulence caused by the motion of moving vehicles on highways is:

a. 2m
b. 4m
c. 8m
d. 10m
e. none of these

52. Which of the following air quality models is most appropriate to use for system planning?

a. SAI
b. DIFKIN
c. APRAC-1A
d. Rollback
e. CALINE2

53. Which of the following air quality models can simulate wind shear best?

a. SAI
b. DIFKIN
c. Rollback
d. APRAC-1A
e. CALINE2

54. Which of the following air quality models uses a lagrangian coordinate system to numerically solve the conservation of mass equation?

a. DIFKIN
b. SAI
c. APRAC-1A
d. Rollback
e. CALINE2